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UNIFYING NOMENCLATURE IN THE PENNSYLVANIAN SYSTEM OF THE ILLINOIS BASIN

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ABSTRACT

Nomenclature in the Pennsylvanian System of the Illinois Basin includes numerous local and regional names that have been applied to correlative units over many years of geological investigation. The Tri-State Committee on Correlations in the Pennsylvanian System of the Illinois Basin was formed by the geological surveys of Illinois, Indiana, and Kentucky to standardize this terminology among the three states. To date, seven stratigraphic names have been recommended to replace 15 existing names. Carthage limestone, West Franklin limestone, Herrin coal, Springfield coal, Houchin Creek coal, Survant coal, and Colchester coal.

INTRODUCTION

Stratigraphic nomenclature of Pennsylvanian rocks in the Illinois Basin includes local and regional names that have been applied to correlative units in the course of many years of geological investigation. During the 1800s and early 1900s, geological surveys were confined primarily to the margins of the basin,

where most of the outcrops are located. After the advent of widespread drilling for oil and gas, numerous records of subsurface geology became available, permitting regional stratigraphic analysis and correlation. It was then apparent that the existence of a Pennsylvanian stratum with more than one name was very common. Although many attempts have been made in the past to systematize terminology in the Pennsylvanian System, a multiplicity of names persists.

During the late 1970s, the need for a systematic review of Pennsylvanian nomenclature became evident. Consequently, the geological surveys of Illinois, Indiana, and Kentucky formed the Tri-State Committee on Correlations in the Pennsylvanian System of the Illinois Basin. This Committee consists of representatives from the three state surveys, with ad-hoc participation by members of the U.S. Geological Survey. The purpose of this committee is to standardize terminology in the Pennsylvanian System among the three states. This paper summarizes the work of the Committee to date. Emphasis thus far has been on selecting appropriate names of key beds for basinwide use. No recommendation is made with respect to stratigraphic rank because of varied usage among the three states.

METHODOLOGY

Committee members have examined three sources of information in arriving at basinwide correlations and recommmendations presented in this paper. First, literature pertinent to the history of nomenclature of a particular unit was reviewed. Next, the unit was traced in the subsurface by means of geophysical logs and plotted on cross sections. Finally, available biostratigraphic data were considered to evaluate their support for the proposed correlation.

Several workers have examined the spore assemblages of Pennsylvanian coals in the Illinois Basin. Palynology of Illinois coals has been investigated by Brokaw (1942), Kosanke (1950), Peppers (1964), Peppers and Pfefferkorn (1970), and Phillips and Peppers (in press). Indiana coals above the Colchester have been examined by Guennel (1952). Peppers (1970 and in press) has investigated coals throughout the basin. In addition, Peppers (1983, personal communication) has a large amount of unpublished data on the palynology of western Kentucky coals.

A principal cross section was constructed using geophysical logs from coal and oil test holes and lithologic descriptions of cores from coal test holes. The line of principal cross section is shown in Figure 1. Copies of this section are available for inspection at each of the three surveys. Spacing of datum points averages about one hole per mile (1.6 km). Datum for the section is the Springfield coal. This section connects areas where earlier work in the basin has established a framework of correlations, where the key units have been identified in the subsurface, and where older existing sections in survey files provide a background of detailed correlation. Other sections were constructed to tie the principal cross section to type areas.

When agreement has been reached on use of a name, a recommendation is made to each state survey. The recommendation contains the history of the name and its synonyms, a description of the work completed by the Committee, and the suggestion of a name (together with type and references sections) for use throughout the Illinois Basin.

PENNSYLVANIAN STRATIGRAPHY

Pennsylvanian strata in the Illinois Basin consist predominantly of shale, siltstone, and sandstone. Many of these clastic units are lenticular and discontinuous and are difficult to correlate from outcrop to outcrop or between drill holes. Units having the most lateral continuity are coals, black shales, and marine limestones.

The lower part of the Pennsylvanian System (Morrowan and Atokan Series) is dominated by sandstone, siltstone, and shale and contains only a few thin and discontinuous coals and limestones. The middle part of the Pennsylvanian (Desmoinesian Series) contains widely indentifiable units. The units easiest to correlate are coals, including such commonly mined ones as the Herrin, Springfield, and Colchester. Coals in the upper part of the Pennsylvanian (Missourian and Virgilian Series), are generally thin, although some are widely traceable. The most widely identifiable strata are limestones (e.g. Shoal Creek/Carthage limestone). Beds in these series tend to be in several localized erosional remnants.

RECOMMENDATIONS

The Committee has recommended names for seven stratigraphic units (Fig. 2) for use throughout the basin. Locations of the type and reference sections are shown in Figure 1.

Carthage Limestone

The Carthage limestone generally is found in a single stratum that is commonly 6 to 8 feet (1.8 to 2.4 m) thick, but can be 20 feet (6 m) thick in some locations. It consists of bluish gray to light gray, finely crystalline limestone that contains diverse marine faunas. Owen (1856) applied the term Carthage to this limestone in western Kentucky where present usage is the Carthage Limestone Member of the Sturgis Formation. The term Shoal Creek was introduced in Illinois by Engleman (1868). Wier and Gray (1961) extended the use of this term to Indiana. In Illinois and Indiana it is now known as the Shoal Creek Limestone Member of the Bond Formation (Fig. 2).

We have correlated the Shoal Creek Limestone Member of Illinois and Indiana with the Carthage Limestone Member of Kentucky based primarily on subsurface geophysical data. These data have substantiated earlier correlations that were based primarily on subsurface data (e.g., Wanless, 1939, 1956; Kosanke et al, 1960). Peppers (1983, personal communication) has correlated the New Haven coal that lies directly beneath the Shoal Creek in Illinois with an unnamed coal that lies beneath the Carthage in western Kentucky. These coals are characterized by the great abundance of *Punctatisporites minutus* and the rather common occurrence of *Alatisporites*. The New Haven (and correlative coals) is also the only coal in the upper part of the Pennsylvanian in the Illinois Basin that contains a significant number of specimens of *Thymospora obscura*.

Because the term Carthage is slightly older, the Committee herein recommends it as a basinwide unit name. We recommend that the type locality for the Carthage, designated by Owen (1856), which is an outcrop in the bank of the Ohio River one mile west of Uniontown, Kentucky, be retained. The type locality for the Shoal Creek, as defined by Kosanke et al (1960), should be retained as a reference locality.

West Franklin Limestone

The West Franklin in the eastern part of the Illinois Basin consists of sparsely fossiliferous to fossiliferous limestone interbedded with shale and may contain one or more thin coal beds. In western Kentucky up to four separate limestone strata with thinner intervening shales have been reported, but in eastern Illinois and Indiana a maximum of three strata is known to be present. Total thickness of the West Franklin commonly ranges from 10 to 20 feet (3 to 6 m), but the limestones are lenticular and the total interval thickens to as much as 50 feet (15 m) in parts of western Kentucky.

Owen (1839 p. 8) was the first to mention the limestone exposed in the high bank of the Ohio River at West Franklin, Posey County, Indiana. Lesquereux (1862, p. 296-297) described the stratigraphy of the limestone at West Franklin and referred to it as the West Franklin limestone. Collett (1884, p. 61-62) adopted Lesquereux's name. Shrock and Malott (1929) traced this limestone south into Kentucky and west into Illinois. Easton (1943) referred to the limestone in eastern Illinois as the West Franklin Limestone. Current usage (Fig. 2) in Indiana is West Franklin Limestone Member of the Shelburn Formation (Shaver et al, 1970) and in Illinois, West Franklin Limestone Member of the Modesto Formation (Willman et al, 1975). In Kentucky, Norwood (1878, p. 319-320) used the term Madisonville for a limestone in Hopkins County that is correlative with the West Franklin. That term has been in use in western Kentucky for many years; the limestone currently is known as the Madisonville Limestone Member of the Sturgis Formation (Kehn, 1973).

Our correlation of the West Franklin and Madisonville limestones is based on detailed analysis of geophysical logs, and it substantiates earlier correlations (e.g., Collett, 1884; Wanless, 1939; Kosanke et al, 1960).

We recommend that the term West Franklin be used for this limestone throughout the tri-state area of the Illinois Basin. The term West Franklin is slightly older than Madisonville and is presently used in two of the three Illinois Basin states. We also recommend that the type section be the exposures described by Lesquereux (1862) and Collett (1884) near the town of West Franklin in the SE1/4 SE1/4 Section 24, T. 7 S. R. 12 W., Posey County, Indiana.

Herrin Coal

The Herrin is one of the thicker and more widespread coals in the Illinois Basin. It ranges in thickness from a few inches to as much as 15 feet (4.5 m); over broad areas it averages 6 to 7 feet (1.8 to 2.1 m). It generally is characterized by a prominent claystone parting (the "blue band"), normally 1 to 3 inches (2.5 to 7.6 cm) in thickness, that occurs in its lower portion.

The term Herrin was formally applied to this coal in Illinois by Shaw and Savage (1912, p. 6). Its present designation is the Herrin (No. 6) Coal Member (Carbondale Formation) (Willman et al, 1975). The term Herrin Coal Member (Dugger Formation) was introduced for usage in Indiana by Wier (1970). Ever since Owen first described this same coal in western Kentucky, it has been called the No. 11 coal in this area. In 1916 Lee called this coal the Herrin or No.11 coal, but other workers preferred No. 11 coal and the term remained until Williamson et al (1979) reapplied the name Herrin to this coal. It is now known in western Kentucky as the Herrin coal (W. Ky. No. 11).

Correlation of the Herrin Coal Member of Illinois and Indiana with the Herrin coal (W. Ky. No. 11) of Kentucky has been based on physical correlations made by earlier workers (e.g., Lee, 1916; Wanless, 1939). The cross section constructed by this committee, based primarily on subsurface geophysical logs, confirms these earlier correlations. Peppers (1983, personal communication) has examined samples of this coal from Indiana and western Kentucky, as well as Illinois (Peppers, 1970). The Herrin coal is dominated by *Lycospora granulata; Laevigatosporites minutus* is subdominant. *Schopfites* is absent from the Herrin, although it is present in the underlying Briar Hill coal in Illinois and Bucktown coal in Indiana. In contrast, the next overlying coal bed, the Jamestown coal, has a low diversity of spores, containing more *Vesicaspora wilsonii* and *Cappasporites distortus*, fewer *Lycospora*.

The committee recommends that the basin-wide useage of this term be continued as it presently is in the nomenclature of the three Surveys. The type section for the Herrin was established by Shaw and Savage (1912). This section comprises subsurfaces exposures in mines near Herrin, Williamson County, Illinois.

Springfield Coal

This coal is the most widely recognized and mined coal in the Illinois Basin. It is commonly 4 to 8 feet (1.2 to 2.4 m) thick. In southwestern Indiana, it reaches 13 feet (4 m) in thickness. In southeastern Illinois and southwestern Indiana, where this coal is overlain by the gray, silty Dykersburg Shale Member and correlatives, it locally is split by shale partings that are in places several tens of feet thick. Throughout the remainder of the basin, it is overlain by a black fissile shale.

The terms Mulford and No. 9 coal were first used by Owen (1856, p. 15) for this coal in western Kentucky. After Owen, however, this term was not used again, and the coal was simply known as the No. 9 coal until Williamson et al (1979) reinstituted the term Mulford coal (W. Ky. No. 9). In Illinois this coal until very recently had two names, the Springfield (No. 5) Coal Member (Worthen, 1883) and the Harrisburg (No. 5) Coal Member (Shaw and Savage, 1912). The term Springfield will be used throughout Illinois in future publications of the Illinois State Geological Survey (Trask, Palmer, and Peppers, 1983). Use of the term Springfield was extended to Indiana by Wayne, Johnson, and Keller (1966), who cited an unpublished manuscript. Burger and Wier (1970) formalized this name in Indiana to Springfield Coal Member (V).

The committee's correlation of the Springfield coal in Illinois and Indiana with the Mulford coal in Kentucky is based in part on subsurface physical correlations, which confirm other earlier physical correlations of the coals (e.g., Worthen, 1868; Ashley, 1909). Peppers (1983, personal communication) has also used palynology to correlate the Springfield and Mulford coals. Spore assemblages in this coal are about equally divided between those spores that were produced by lycopods and those produced by ferns. *Anapiculatisporites spinosus* reaches its maximum abundance in this coal. *Laevigatosporites globosus, L. minutus, Thymospora pseudothiessenii*, and *Schopfites* are all common.

The committee recommends the term Springfield as the unit name for this coal throughout the Illinois Basin. It already has widespread use in Illinois and Indiana. We also recommend that the type section for the Springfield remain as established by Wanless (1956). This section comprises subsurface exposures in abandoned coal mines in Section 16, T. 16 N., R. 4 W., Sangamon County, Illinois.

Houchin Creek Coal

This thin but extensive coal ranges up to 4 feet (1.2 m) thick in southwestern Indiana, southern and northern Illinois, and western Kentucky. It is generally underlain by a thin underclay and overlain by a thick, black fissile shale.

The term Houchin Creek was introduced by Fuller and Ashley (1902, p.2) for the coal that is prominent along Houchin Creek in Pike County, Indiana. This unit had previously been designated Coal IVa by Ashley (1899, p. 90). Present usage in Indiana (Shaver et al, 1970) is the Houchin Creek Coal Member (IVa) of the Petersburg Formation (Fig. 2). Wanless (1931) applied the term Summum to this coal in western Illinois. In western Kentucky the coal was referred to as the 8b coal (Glenn, 1912) until Beard and Williamson (1979) introduced the term Ruff. The Summum (No. 4) Coal Member and Ruff coal (W. Ky. No. 8b) have been correlated with Houchin Creek by many previous workers (e.g., Wanless, 1939; Kosanke et al, 1960; Peppers, 1970).

We correlated the Houchin Creek, Summum, and Ruff coals using subsurface geophysical logs to confirm earlier physical correlations. Though the Houchin Creek is difficult to distinguish palynologically from the Springfield, Peppers (1983, personal communication) has been able to separate the two based on higher frequency of *Alatisporites* and *Reinschospora* in the Springfield and higher frequency of *Verrucosisporites*, *Lophotriletes*, *Dictyotriletes*, *Recticulatesporites*, and *Vesicaspora* in the Houchin Creek.

We recommend the older term Houchin Creek for use throughout the Illinois Basin and a section described by Wier (1961, unpublished manuscript) in the SE1/4 NE1/4 SW1/4 Section 3, T. 3 S., R. 7 W., Pike County, Indiana, as the type section. The exposure is in the abandoned highwall of a surface mine now on property owned by the state of Indiana. In 1980, a reference core of the Houchin Creek (Indiana Geological Survey drill hole SDH 306, 26.8-27.2 feet) was taken from the SE1/4 NE1/4 NW1/4 Section 2, T. 2 S., R. 7 W., Pike County. We also recommend that the alternate type section (Peppers, 1970) for the Summum be retained as a reference section.

Survant Coal

The Survant is a widespread coal in the Illinois Basin. It commonly ranges from 1 to 4 feet (0.3 to 1.2 m) thick, but in places it is as thick as 8 feet (2.4 m). It is generally underlain by a thin underclay and overlain by a dark shale. The coal commonly has a shale parting no more than a few feet thick, but the parting increases to as much as 30 feet (9 m) thick in the northern part of the coal field in Indiana and in southeastern Illinois.

Fuller and Ashley (1902) introduced the term Survant for exposures in the SW1/4 NE1/4 Section 2, T. 2 S., R. 7 W., near the now abandoned town of Survant in Pike County, Indiana. Present designation in Indiana is the Survant Coal Member (IV) of the Linton Formation (Fig. 2). Many workers have correlated the Survant with the Well coal (W. Ky. No. 8) of Kentucky and the upper bench of the Survant with the Shawneetown Coal Member of Illinois.

We have correlated the Survant and Well coals using subsurface geophysical logs. We have also correlated these coals with two benches of coal formerly called the No. 2A Coal in eastern and southeastern Illinois. The upper bench is presently designated Shawneetown Coal Member and the lower bench is unnamed. Peppers

(1970) has also correlated these coals based on palynology. *Laevigatosporites globosus*, *Schopfites*, and *Alatisporites* are abundant in the Survant and equivalent coals. A large number of species that are not present in the Houchin Creek or Springfield have been recorded from the Survant (Peppers, 1983, personal communication).

We recommend Survant as the name for this coal throughout the Illinois Basin. In addition to the Survant's being the oldest of three terms, Kosanki et al (1960, p. 34-35), when naming the Shawneetown coal, indicated the Shawneetown to be the lower of two coals called 2A but gave a depth in the core which subsequently was found to correspond with the Colchester coal. Peppers (1970) redefined the Shawneetown as the upper bench of coal. The Well coal has no type section, and was named for its having been encountered in water wells. Type section for the Survant is that designated by Fuller and Ashley in Pike County, Indiana. A reference core for the Survant was taken from near the type exposure by the Indiana Geological Survey (SDH 306, 83.3-85.2 feet) in 1980).

Colchester Coal

The Colchester is a relatively thin, highly persistent coal widely used in the Illinois Basin as a stratigraphic marker. It was considered by Wanless (1962, p. 36) to be ". . .probably the most uniform stratum in the entire basin." It is 2 to 3-1/2 feet (0.6 to 1.1 m) thick in western and northern Illinois, where is has been extensively mined; however, the coal in southern and eastern Illinois and in Indiana is thinner, ranging from a fraction of an inch to as much as 3 feet (0.9 m). Except in the northern part of the Illinois Basin, the Colchester is overlain by a distinctive black shale that is easily identified on geophysical logs of subsurface strata.

Worthen (1866, p. 59) applied Coal No. 2 to this coal in Madison County, Illinois. The Colchester was named by Worthen (1868, p. 11) from exposures in McDonough County, western Illinois. Wanless (1939) combined Worthen's terms and named it the Colchester (No. 2) coal and later (1956, p. 10) designated as the type section exposures near Colchester (Secs. 12 and 13, T. 5 N., R. 4 W., McDonough County). Kosanke et al. (1960) elevated the coal to member status in the Carbondale Formation of Illinois. It is corrently known in Illinois as the Colchester (No. 2) Coal Member (Fig. 2).

In Indiana Wier and Gray (1961) adopted the term Colchester Coal Member (IIIa) of the Linton Formation for this coal, which previously had been designated Coal IIIa by Ashley (1909, p. 55-57). The name Colchester has not been used in the western Kentucky part of the Illinois Basin. However, the Colchester of southern Indiana and southeastern Illinois can be traced in the subsurface directly into northwestern Kentucky, where the unit was formerly identified by various authors as the "Schultztown," the "S," or the "No. 7" coal bed. The correlation of the Colchester from the subsurface in western Kentucky with surface exposures is controversial and has not been definitely established. Consequently the term is currently restricted to designation of the subsurface coal in western Kentucky.

The committee used geophysical logs from oil-and-gas test holes to confirm correlation of the Colchester coal throughout its known occurrence in the Illinois Basin. About 160 species of miospores have been recorded from the Colchester coal (Peppers, 1983, personal communication). The spore assemblage is dominated by *Lycospora*. *Florinites* is less abundant in this and higher coals than in

coals below. *Laevegatosporites globosus* is less abundant in the Colchester than in the Survant, Houchin Creek, or Springfield coals. *Schopfites* is rare in coals immediately below the Colchester but is common in the Colchester.

We recommend the use of the name Colchester for this coal throughout the Illinois Basin. We also recommend that the type section established by Wanless (1956, p 10) be retained. A reference core (SDH 306) taken by the Indiana Geological Survey from Pike County, Indiana, contains Colchester coal at 140.6-141.6 feet. In Kentucky the Colchester occurs at the interval 88.52 to 88.85 feet in Kentucky Geological Survey reference core hole, W. Ky. DD15.

CONCLUSIONS

The Committee has extensively reviewed the usage of 15 stratigraphic names in the tri-state region of the Illinois Basin. We find ample and convincing evidence that warrants the formal adoption of seven names: Carthage limestone, West Franklin limestone, Herrin coal, Springfield coal, Houchin Creek coal, Survant coal, and Colchester coal.

The Committee continues to meet twice a year. We also hold occasional informal field trips to examine type localities and critical exposures. We will continue to work toward the achievement of a standardized stratigraphic nomenclature for the Pennsylvanian System for use throughout the Illinois Basin.

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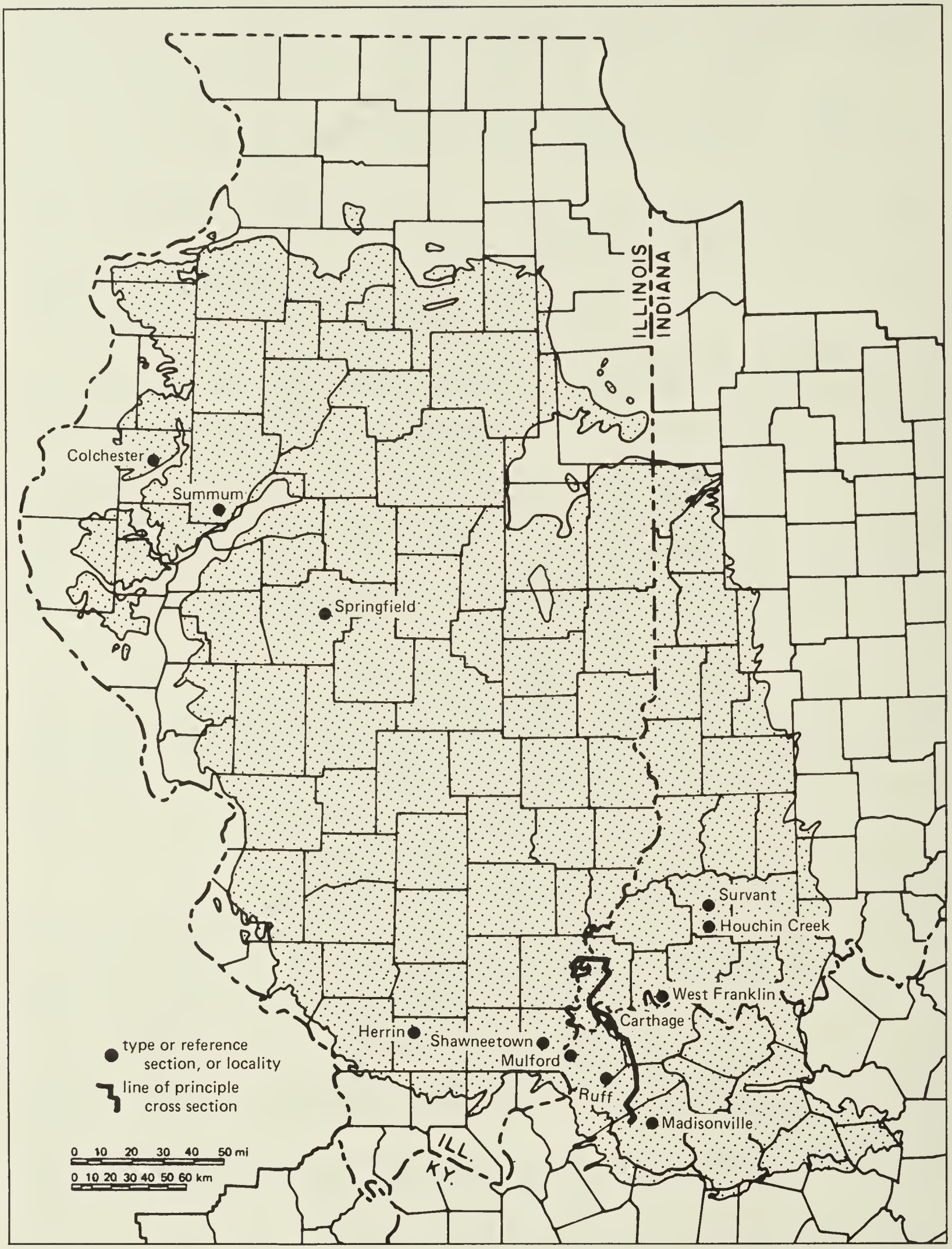

Fig. 1. Map of the Illinois Basin showing extent of Pennsylvanian rocks and locations of type and reference sections used in this report.

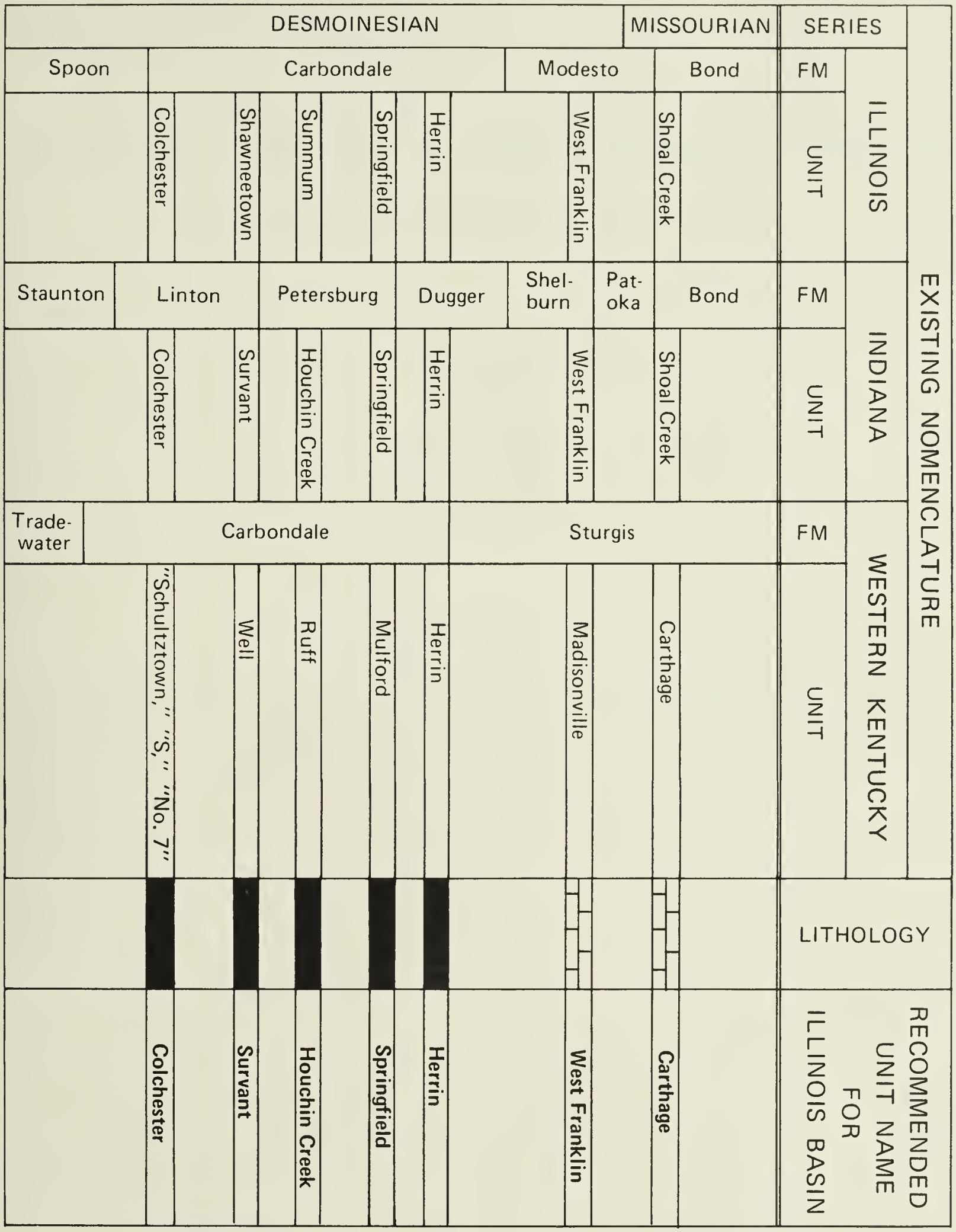

Fig. 2. Existing and recommended nomenclature for selected Pennsylvanian units in the Illinois Basin.

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ECOLOGY OF BALD EAGLES WINTERING IN SOUTHERN ILLINOIS

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ABSTRACT

The population size, food habits, distribution and habitat of wintering bald eagles (*Haliaeetus leucocephalus*) were investigated at Union County and Horseshoe Lake Conservation areas during 1979-1981 and Crab Orchard National Wildlife Refuge during 1980-1981. Eagles arrived in southern Illinois late October with estimated peak populations of 180-200 occurring, dependent on weather conditions, in January or February; eagles departed by early March. Immatures predominated wintering populations; but adult and immature subpopulations displayed similar fluctuations in numbers. Morning and evening roost counts provided reliable estimates of total population size while motor counts yielded data on eagle distribution, activities and habitat utilization.

Diurnal perch sites near shallow water areas were utilized most during early winter; with ice cover on waters, eagles shifted to sites of open water where waterfowl were concentrated. Carcasses of Canada geese appeared the principal food at this time. Though eagle attacks were witnessed on injured or dying waterfowl, none were successful. During late winter, eagles appeared less reliant on refuges as feeding areas; this may have been associated with spring migration. Food availability was considered a major influence on selection of diurnal perch sites; protection from winds and insulation from human disturbance seemed secondary. Communal roost areas offered shelter from prevailing winds by surrounding vegetation and were associated with standing water. Most eagles left roosts by sunrise; the peak of return was 10 minutes after sunset.

The bald eagle population wintering in the southern Illinois region has increased significantly since the 1950's. Areas used for roosting and feeding are largely associated with refuges and concentrations of waterfowl. Management should ensure feeding and roosting areas are closed to public access during periods of eagle use; and emphasis should be on protection of trees affording roosting and feeding needs

and those adjacent that served as windbreaks. Further, because of the potential for lead poisoning, hunter use of lead shot should be banned.

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INTRODUCTION

Approximately one-third of the bald eagle population wintering in the United States utilizes the upper Mississippi Valley (Snow 1973). Dams on the Mississippi River and its tributaries north of St. Louis regularly provide open water and feeding sites. The large numbers that congregate along the river have been studied extensively during the last 20 years (Southern 1963, 1964; Grewe 1966, Jonen 1973, Steenhof 1976, Griffin 1978, Dunstan 1979). In southern Illinois, the Mississippi River may be of less importance where Crab Orchard National Wildlife Refuge and the Union County and Horseshoe Lake Conservation areas support large populations of wintering bald eagles and waterfowl. Although bald eagles are principally piscivorous (Bent 1937, Broley 1947), use of waterfowl as a food resource has been reported by Midwest researchers (Steenhof 1976, Griffin et al. 1980 and 1982) and is presumed important in eagle use of refuges. Casual observations (Southern 1963, 1964) provide the only information for wintering eagles in the southern Illinois region prior to this study. The objectives of this research attempt to characterize winter bald eagle populations, their food habits and their habitat use.

METHODS

Research was conducted on three wildlife refuges in southern Illinois. Union County Conservation Area (UCCA) and Horseshoe Lake Conservation Area (HLCA) were investigated November 1979-March 1980 and September 1980-March 1981. Observations at Crab Orchard National Wildlife Refuge (CONWR) were restricted to November 1980-March 1981.

Union County (2,480 ha) and Horseshoe Lake (3,160 ha) are managed as refuges and are located in the Mississippi River Floodplain. The former site has numerous shallow lakes and ponds (320 ha), while the latter (960 ha) is the only permanent body of water on that area; about half of the available acreage on both sites provides winter forage for Canada geese (*Branta canadensis*). Crab Orchard National Wildlife Refuge includes Crab Orchard Lake (17,200 ha) with the remaining acreage a mosaic of croplands, old fields, forests, and flooded timber. Dominant trees include cottonwood (*Populus deltoides*) and ash (*Fraxinus* spp.) at Union County; Bald Cypress (*Taxodium distichum*) and tupelo gum (*Nyssa aquatica*) at Horseshoe Lake; and mixed oats (*Quercus* spp.) and hickories (*Carya* spp.) at Crab Orchard.

A modified car strip census (Craighead and Craighead 1956) was driven by one observer at speeds between 24 and 32 km/hr on all-weather roads at state refuges. The large size of Crab Orchard Lake coupled with limited shoreline visibility made a car strip census impractical so observations were restricted to shoreline vantage points. Censuses were between 0800-1000 hrs and 1400-1600 hrs CST under vari-

ous weather conditions, excluding days of limited visibility. Duration for each census was 1 hr at UCCA and HLCA and 1.5 hrs at CONWR.

Information on behavior and location of all eagles seen was recorded on forms and maps. A 15-60x spotting scope and 7 × 35 binoculars facilitated observations and minimized eagle disturbance. Birds displaying a white head and tail were considered adults; immatures were discriminated from golden eagles by plumage. Activities were divided into flying, soaring, and perching; flights from previously-censused areas were not recorded to minimize duplication. Perches were classified by height and snags were noted when used. Prevailing weather conditions (cloud cover, ice cover, wind speed and direction) were documented for each census period.

Diurnal habitat use was assessed from motor count observations. As eagles were generally associated with open water, those perched along lake and pond shorelines were used to determine areas of use and temporal changes in distribution. It was not possible to monitor the Mississippi River; hence, its believed importance was not accounted for.

Roost counts were conducted from blinds constructed 50-150 m from roost sites. Location of roosts resulted from observing flight patterns at sunrise and sunset (Lish and Lewis 1975). Confirmation was based on the presence of fecal materials, pellets, and feathers beneath roost trees. Observations were made either 1 hr before sunset until dark or 1 hr before sunrise until most eagles had left the roost. Counts at roost were made within 24 hrs of car censuses.

Species composition and community structure of dominant woody vegetation were analyzed for each roost. Species density, basal area, frequency and canopy height were determined using .03 ha circular plots. Understory vegetation was not considered if the diameter at breast height (DBH) was under 10 cm; 15 random plots were sampled at UCCA and CONWR, and 10 at HLCA. Data gathered for roost trees included species, height, DBH, and condition which was subjectively categorized as living, dead, and dying.

Foods utilized were determined by analyzing pellets collected beneath roost trees (Errington 1932) and examining carcasses fed upon by eagles. Castings were force-air dried at 65°C for 6-36 hours (depending on pellet size and moisture content) in a Fischer Isotemp Model 340. Mammalian and avian remains were identified by guard hair and contour feather characteristics in conjunction with other pellet materials (bones, claws, skin, etc.). Data were supplemented by observations of foraging and feeding eagles. Unfortunately, the almost complete digestion of fish permitted little evaluation of this important food.

RESULTS AND DISCUSSION

Population Fluctuations

Interpretation of eagle counts was dependent on census technique; motor counts reflected numbers along a limited area bordering the route. Peak numbers recorded often reflected large concentrations of eagles around waterfowl or fish carcasses and rarely represented an adequate index to population levels for a given time. Roost counts were the most reliable estimates, especially after mid-November (Figure 1) even though early fall migrants often roosted singly in trees outside the censused roost sites.

Because data for 1979-80 were not obtained prior to November (Figure 1), emphasis on population levels is placed on the 1980-81 roost censuses. During 1980-81

field studies were initiated 28 September; the first sightings were 2 adult eagles on 28 October at UCCA and 1 adult on 4 November at HLCA. The dates of arrival in southern Illinois are similar to those of other wintering areas in the Midwest (Hallaron 1960; Johnson 1961; Southern 1963, 1964; Jonen 1973; Vian and Bliese 1974) as well as those at more northern latitudes (Hancock 1964, Servheen 1975, Nye and Suring 1978). This similarity in arrival times suggests weather has a minor influence on the movement of early fall migrants. Also, availability of suitable habitat did not appear an important factor as early arrivals in transit to southern Illinois passed many northern wintering grounds (Fawks 1961; Southern 1963; Ingram 1965; Grewe 1966; Dunstan 1970, 1979; Jonen 1973; Vian and Bliese 1974). Gerrard et al. (1978) suggested bald eagles tend to return to the same wintering areas year after year; first-year birds may then follow older eagles to traditional wintering grounds. It has also been postulated that in the Midwest subadults migrate south earlier than adults (Southern 1963, Sprunt and Ligas 1966). Although the first fall arrivals at both UCCA and HLCA refuges were adults, no significant difference in arrival times was evident between age classes.

Eagle numbers gradually increased November through late January to early February (Figure 1); in 1979-80, population peaks were 71 at UCCA on 19 February and 78 at HLCA on 8 February. Comparison of population trends suggested that some eagles may have shifted from HLCA to UCCA in mid-February (Figure 1). In 1980-81, populations peaked at 79 at UCCA and 77 at HLCA on 23 January. At these peak levels; 24% were adults at UCCA and 35% at HLCA.

In contrast to populations at UCCA and HLCA, the population levels were lower at CONWR (Figure 1); the peak (29) was mid December followed by a general decline through March. Ice cover (50-90%) on Crab Orchard Lake during December and January probably influenced the decline in numbers by reducing foraging areas. The Mississippi River, which provided open water near UCCA and HLCA was believed used for feeding when refuge impoundments were frozen. High numbers of eagles have also been noted on wintering areas with open water on more northern segments of the Mississippi River (Southern 1963, 1964; Jonen 1973).

The number of eagles dropped rapidly at UCCA and HLCA during late January (Figure 1); these declines continued through February and few were seen after early March. Increases to peak numbers were considerably slower (3 months) than subsequent declines (1 month). A heightened sensitivity of mature birds to spring changes in photoperiod (Servheen 1975) could have contributed. But, rapid declines might also reflect a low influx of spring migrants from southern wintering areas.

Habitat Utilization

Eagles selected tall trees with large horizontal branches for feeding and loafing. Perch sites above 7 m were consistently used (85%, N = 944); most adults perched above 15 m (47%, N = 419), while immatures usually selected sites between 7 and 15 m (51%, N = 525). Generally, perches provided an unobstructed view in at least one direction and allowed easy routes for takeoff and landing. Eagles preferred snags (49%, N = 903), especially those near large bodies of water.

Food availability was considered the major influence on distribution of eagles at each refuge. Newton (1979) believed that raptors dependent on poikilotherms for prey moved farthest south because seasonal temperature variations had the greatest impact on food availability. Hence, piscivorous birds generally winter near

areas offering open water (i.e., reliable food sources) through most of the winter. During early winter, eagles consistently used perches near ponds and borrow pits; apparently, fish were more easily captured here than in deeper waters. Subadults, which may be less efficient at capturing fish, comprised 73% of the observations (52% of population) at these sites. Large bodies of water were more often used by adults. During midwinter, increases in numbers along lake shorelines seemed most associated with the availability of open water and waterfowl carcasses. Presence of Canada geese was associated with 48% of sightings of perched eagles; such flocks of geese usually numbered 1500 or more. This relationship may have been coincidental as both eagles and waterfowl congregated near open bodies of water during mid-winter. Few eagles used refuge foraging areas during late winter; the initiation of the spring migration of geese may have diminished their importance to eagles.

The impact of human activities has been well documented (Servheen 1975; Stalmaster and Newman 1978; Steenhof 1976; Vian and Bliese 1974) and reviewed by Steenhof (1978). The use of diurnal perch sites at HLCA was impacted by human activity during 1980-81. There was a marked decrease in eagle use of perch sites adjacent to a road open to vehicular traffic throughout most of the winter. This was in sharp contrast to 1979-80 when the road was closed and perch sites were consistently used. Moving traffic was often tolerated; but, eagles flushed when vehicles stopped or people approached on foot. Most of the dirunal perch sites at UCCA and CONWR were in areas of restricted access.

Roosts were located on relatively level terrain where adjacent trees provided protection from prevailing northwesterly winds. Tree species used were not consistent between refuges (Table 1). Cottonwood (*Populus deltoides*) snags dominated the UCCA roost sites; this species is commonly used by eagles in the Midwest (Southern 1963, Lish and Lewis 1975, Steenhof 1976, Griffin et al. 1980 and 1982). Snags bordered by live trees were most used. Sycamore (*Platanus occidentalis*), frequently used on more upland sites (Jonen 1973, Lish and Lewis 1975), was the favored roost tree at CONWR. The bald cypress-tupelo gum association was unique to the HLCA roost; but, tupelo was not used probably because it was seldom over 10 m tall. Most roost trees at all areas were large, easily recognized from the air, possessed stout horizontal branches, and offered good visibility over the surrounding terrain.

Southern (1963) reported that eagles roosted singly or in small groups in northern Illinois; but, only early migrants roosted singly in southern Illinois. Edwards (1969) proposed that communal roosting occurred when roosting trees were scarce. Although availability of suitable trees was not believed limiting in southern Illinois, possible competition for favored perch sites may have limited the number of birds within a roost. All roosts in southern Illinois were associated with water, had prominent trees, were bordered by open areas, and usually were insulated from human disturbance.

Lish and Lewis (1975) reported that in Oklahoma most eagles returned to roosts 40 minutes before sunset; in this study they arrived in greatest numbers 5-25 minutes after sunset (Figure 2). Upon entering roost trees, immatures perched in peripheral trees and later shifted to more central roost positions. In the morning, most immatures flew once again to peripheral perches before leaving roosting sites. Adults selected central perches upon entering the roost and left directly in the morning. The major exodus from roosts was between 5 to 35 minutes before sunrise (Figure 2).

Foods and Feeding Habits

In 1979-80, 89 pellets were collected beneath the UCCA roost and 867 pellets were gathered in 1980-81 at UCCA, HLCA, and CONWR. All pellets from 1979-80 were analyzed and a stratified random sample of 150 pellets (50 per roost) was analyzed from 1980-81. Avian remains were most common in eagle castings and typically contained feathers and bone fragments; tarsal skin, claws, dertrum, and gizzard plates were also found. The most common species was Canada goose (234 pellets); mallard (*Anas platyrhynchos*) (27 pellets) represented the only other species of significance (Table 2). Hair and bone of rabbit (*Sylvilagus* spp.), white-tailed deer (*Odocoileus virginianus*), and muskrat (*Ondatra zibethicus*) occurred in a few pellets. Four pellets contained fish scales but fish were generally completely digested (Lish and Lewis 1975). Many studies of bald eagle diets suggest not only great variability in food habits but also great difference as to that recorded in stomachs as compared to cast pellets (Imler and Kalmach 1955).

Because of concern for secondary lead poioning, eagle pellets were fluroscoped. Lead and/or steel shot was exclusively associated with pellets containing waterfowl remains; Canada goose was the principal species (84% of pellets). Of the shot recorded, 89% was lead. There was no correlation between incidence of shot and gizzard plates; hence, most shot was probably initially imbedded in body tissues of waterfowl. Approximately 6% of the pellets yielded lead/steel shot which contrasted markedly with the 50-60% rate for lead reported by Dunstan (1974) in northern Illinois and 71% recorded in Utah (Platt 1976).

Waterfowl carcass feeding, (largely Canada geese) evident November through mid-February, was most frequently observed when there was partial ice cover of impoundments. Immature eagles, less adept at capturing live prey (Sherrod et al. 1967), seemed to rely more heavily on carcasses as a food source. Subadults, which comprised 72% of the individuals seen at carcass sites, made up but 52% of winter populations.

The most obvious field signs associated with eagle scavenged waterfowl carcasses were the large tracks which could not be confused with any other wintering raptor. Feathers from the breast, abdomen, neck, or back were first removed from fresh carcasses; often goose carcasses were decapitated. Once the body cavity was opened, visceral organs were consumed before muscle. Remains from heavily scavenged carcasses consisted of bones and primary feathers; skeletal remains were principally the wing, pectoral girdle, and vertebral column.

Feeding by eagles on carcasses of bowfin (*Amia calva*), big-mouth buffalo (*Ictiobus cyprinellus*), and shortnose gar (*Lepisosteus platostomus*) was also recorded. Excluding the head, buffalo and bowfin were completely consumed while shortnose gar were only eviscerated.

Six attacks on live waterfowl, made predominantly by immatures, were witnesssed with three instances involving apparently healthy waterfowl. A male mallard and a female hooded merganser (*Lophodytes cucculatus*) on water were attacked by an immature eagle on separate occasions; both escaped by diving. Another incident involved an aerial pursuit in which a Canada goose easily outdistanced an immature eagle. The remaining observations were on crippled waterfowl incapable of flight. An immature made a single pass about 3 m above a Canada goose nearly frozen in ice. On another occasion, a female mallard with a broken wing escaped an immature's attack by running across the water. An adult and two immature eagles participated in the only incident in which a waterfowl was struck from an aerial

attack by an adult eagle. The impact knocked the duck onto it's back, after which the eagle landed upon it's breast and plucked a number of breast feathers. Within a minute, the adult stepped off and two immatures standing nearby immediately took to the air and twice lifted the mallard roughly 7 m and dropped it onto the ice. The duck eventually returned to an upright position but was unable to walk; no further attempts were made to pursue feeding on it.

Researchers in northern Illinois (Southern 1963, 1964; Jonen 1973), Nebraska (Vian and Bliese 1974), and South Dakota (Grewe 1966) believed the association between wintering eagles and waterfowl to be coincidental as both relied on open water. However, studies in Oklahoma (Griffin 1978) and South Dakota (Steenhof 1976) indicated that eagles were active predators on waterfowl. In southern Illinois, eagles fed principally on waterfowl carrion; most attacks observed on healthy waterfowl were by immatures and were unsuccessful. It was not presumed that injured or diseased ducks, especially those incapable of flying or diving, were not vulnerable to predation. However geese, even in weakened condition, were apparently too large to be readily taken.

Observations of eagles capturing fish were similar to those reported by Southern (1963); the most prevalent and successful method was to swoop from a low perch and secure a fish with one or both feet. Eagles were also noted to soar in tight circles 10-15 m over open water and drop to capture fish. Adult eagles, believed to be fishing, were occassionally observed gliding 1-3 m over open water; however, no successful captures during passes were recorded. Eagles were consistently observed fishing at shallow water impoundments and Mississippi River backwaters; gizzard shad (*Dorosoma cepedianum*), 15-25 cm in length, was the only fish observed taken. Additional species were probably caught but were not identified.

SOME SUMMARY GENERALIZATIONS

The numbers of eagles now appearing each fall and winter in the southern Illinois region are many times that noted during 1949-1970. The bald eagle is probably re-establishing a population distribution in the Mississippi River Valley similar to its historic pattern. However, with man-induced developments as evidenced by dams and impoundments on the River and the created waters of Rend Lake, Crab Orchard, Union County, and Horseshoe Lake refuges, a once probably dispersed population now reflects focal points of concentration due to localized food supplies as provided by open waters below dams and concentrated populations of waterfowl, especially Canada geese. The availability of the latter is further enhanced by concentrated hunting which yields a considerable food source as injured and unretrieved dead birds. The developing security for this eagle population is further attested by the 1-3 nesting pairs each year recorded in southern Illinois since the mid 1970s. This recurrence of the bald eagle is to some degree a consequence of planned events associated with refuge development and management. However, significantly important has been the combined efforts of many who perserved in activities to protect the eagle from a variety of vicissitudes imposed by humans. Although many aspects of this raptor's recovery are now in place and subject of widely-prevalent management practices, continued mortalities are still unanswered by proper constraints. Presumably, man will not repeat the DDT episode; but all chemical use in our environment must be viewed with caution. However, the con-

tinued aversion of imposing a ban on use of lead shot is adequately documented a serious, imminent threat (Pattee and Hennes 1983); if not the entire upper Mississippi River Valley, at least several localized settings are suggested by this study as well as others to be potential, if not actual, problems. Further, zealous efforts to impact sites useful for expansion of wintering eagle needs, and the desire of the public to have a close look at feeding and roosting eagles, are locally critical to their best interest. Also, caution in forest harvest practices on state and federal refuges, national forests, and other public holdings must be emphasized as available and acceptable roost sites are unquestionable needs in some areas. Ultimately, even in southern Illinois, availability of suitable nest trees may be a factor to content with.

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Table 1. Tree characteristics of roost sites utilized by eagles at CONWR, UCCA, and HLCA, 1979-81.

Species	Importance Value*		
	CONWR	UCCA	HLCA
Sugar maple (*Acer saccharum*)	104	4	
Red maple (*Acer rubrum*)	16	3	
Box elder (*Acer negundo*)	28	5	
Green Ash (*Fraxinus pennsylvanica*)	3	35	
Sycamore (*Platanus occidentalis*)	29		
Cottonwood (*Populus deltoides*)		41	
Tupelo gum (*Nyssa aquatica*)			105
Bald cypress (*Taxodium distichum*)			95
Snag	6	90	
Total Density	233/ha	400/ha	497/ha
Total Basal Area	39m²/ha	53m²/ha	81m²/ha
Canopy Height	21.38 m	30.56 m	17.94 m
Average Roost Tree Height	31.60 m	30.10 m	21.62 m

*relative density plus relative basal area

Table 2. Food items identified in 239 bald eagle pellets collected beneath roosts at UCCA, HLCA, and CONWR, 1979-81.

Species	Percent Frequency of Occurrence			
	UCCA(89)* 1979-80	UCCA(50) 1980-81	HLCA(50) 1980-81	CONWR(50) 1980-81
BIRDS				
Canada goose (*Branta canadensis*)	82	65	98	80
Mallard (*Anas platyrhynchos*)	6	20	2	6
Widgeon (*Anas americana*)				4
Black duck (*Anas rubripes*)		4		
Unidentified	3	6		4
MAMMALS				
Rabbit (*Syvilagus floridanus*)	6	2		2
Muskrat (*Ondatra zibethicus*)	2	2	6	
White-tailed deer (*Odocoileus virginianus*)				6
Raccoon (*Procyron lotor*)		2		
Grey squirrel (*Sciurus carolinensis*)		2		
Fox squirrel (*Sciurus niger*)	1			
Opposum (*Didelphis marsupialis*)	1			
Unidentified		2	2	4
FISH		2	2	4

*number of pellets analyzed

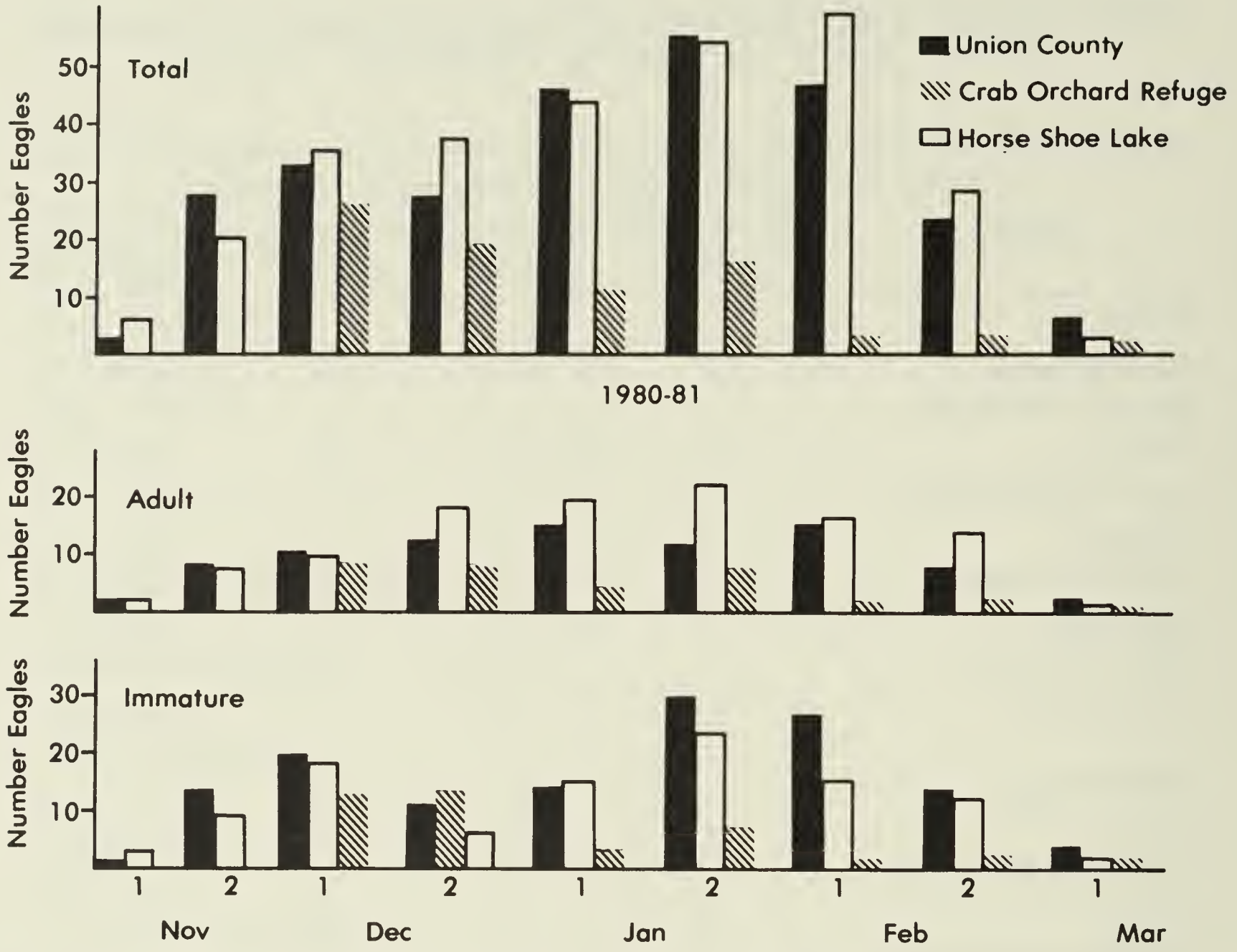

Fig. 1. Eagle populations for November 1980-March 1981, as recorded for UCCA, HLCA and CONWR.

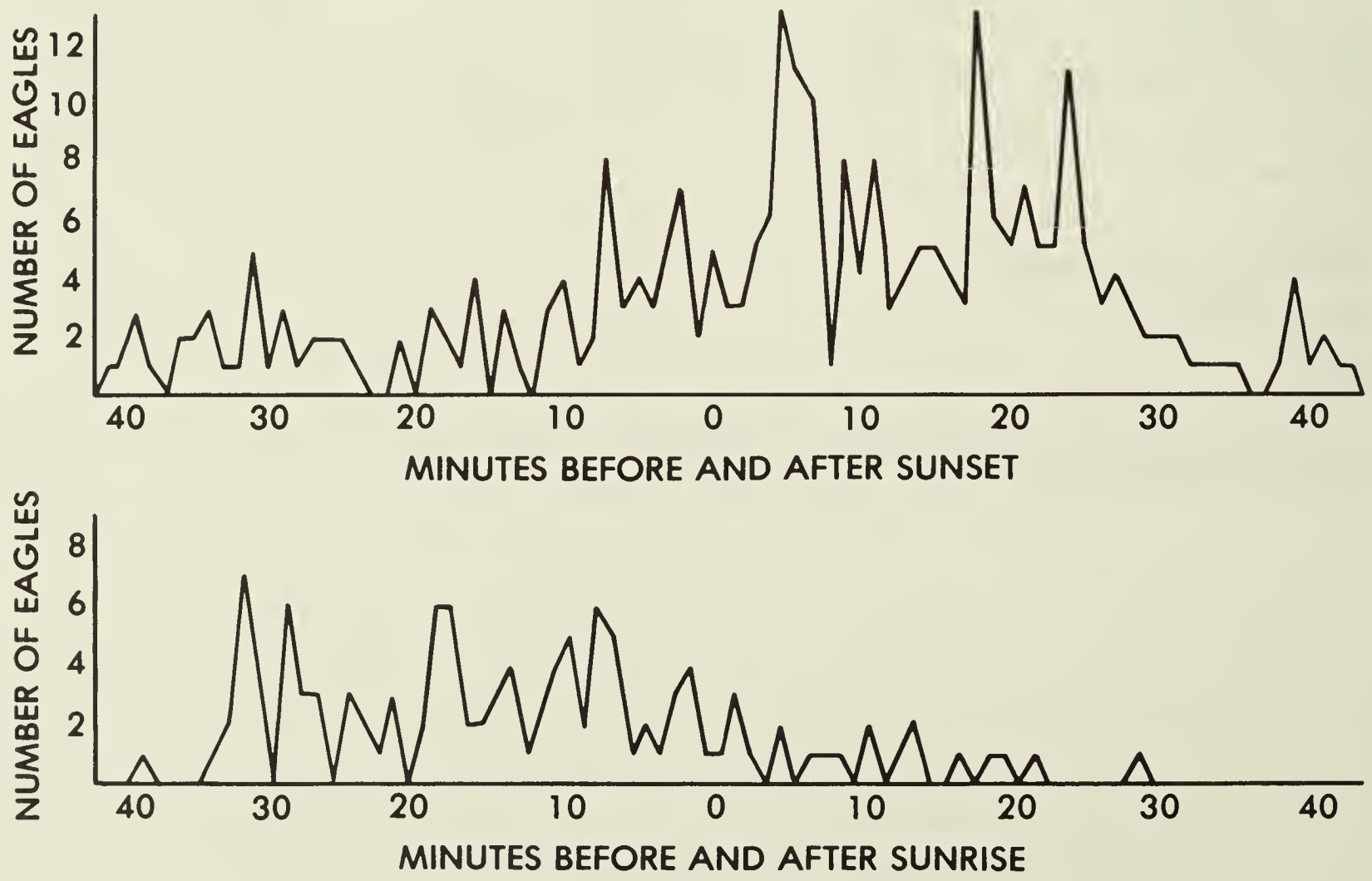

Fig. 2. Arrival and departure times of bald eagles at HLCA, UCCA, and CONWR, relative to sunrise(0) and sunset(0), 1980-1981.

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CYCLIC ANHYDRIDES OF 1,2; 2,3 and 1,8 — DICARBOXYLIC ACIDS OF NAPHTHALENE PRODUCED FROM DICHROMATE OXIDATIONS OF SOLVENT REFINED LIGNITE — A POSSIBLE CLUE TO POLYMER STRUCTURES IN LIGNITE

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ABSTRACT

Solvent refined lignite was oxidized with aqueous sodium dichromate, and produced only three dibasic acids of naphthalene. The total number of dibasic acids of naphthalene are ten, however, only three of these isomers will form cyclic anhydrides (1-2, 2-3, and 1-8 isomers). This study identified the three dibasic acids produced from the oxidation of solvent refined lignite by converting them to their cyclic anhydrides which suggest how the units of naphthalene are connected in lignite structures.

INTRODUCTION

Shechter *et al.* (1965) have shown that aromatic acids can be synthesized in good yields from alkyl substituted aromatic hydrocarbons.

$$\text{2-Methylanthracene} \xrightarrow[250^\circ C]{\text{aq. } Na_2Cr_2O_7} \text{2-Anthracenal carboxylic acid}$$

Hayatsu *et al.* (1975, 1978) have studied the oxidation of coals using aqueous sodium dichromate according to the procedure of Shechter (1965), and have reported an extensive list of condensed ring aromatic carboxylic acids which were identified as the oxidation products from these coal oxidation studies. Hayatsu *et al.* (1978) also reported the results of his basic extraction studies with lignite and reported the

following acids; benzene carboxylic acids (16.6%), methylbenzene carboxylic acids (16.0%), phenolic acids (40.0%) furancarboxylic acids (0.8%), aliphatic dibasic acids (10.8%), terpenoid acids (6.6%) benzo and hydrobenzofuran carboxylic acids (4.3%) and unidentified acids (4.5%). It was interesting to note that no acids of naphthalene were extracted with the 2.5% aqueous sodium hydroxide which he used to extract these acids.

Previously we had reported the results of the study of aqueous sodium dichromate on a North Dakota lignite and its solvent refined lignite (Duty, 1980). This study identifies the aromatic cyclic anhydrides of naphthalene from the solvent refined lignite.

MATERIALS AND METHODS

These anhydrides were analyzed by a gas chromatography-time of flight mass spectrometer (GC-TOFMS). The gas chromatograph was a Perkin-Elmer 3920B gas chromatograph interfaced to the TOFMS with a continually variable split between the flame-ionization detector and the source of the mass spectrometer. The GC column was 15.2 m × 0.57 mm support-coated, open tublar column with an OV-17 substrate. Temperatures were programmed from 100°C to 250°C @ 4°C min^{-1}, with helium as the carrier gas. The high-resolution mass spectral data were obtained with an AEI MS-902 using a PDP-8 computer for data reduction. Samples were also run on the TOFMS with a variable-temperature solid inlet (Hayatsu, 1975). The gc retention times for the 1,2; 2,3 and 1,8-dicarboxylic acids of naphthalene were 34.8 min, 38.3 min, and 38.8 min, respectively. Mass spectrometer readings produced molecular ion peaks at 198, base peak at 126 and daughter ion at 162 for each. Standards were run with 1,8-naphthalic anhydride (Aldrich Chem. Co.) and 2,3-naphthalic anhydride produced by refluxing 2,3-naphthalene dicarboxylic acid (Aldrich Chem. Co.) with acetic anhydride. Dipole moments were calculated for 1,8-naphthalic, 2,3-naphthalic, and 1,2-naphthalic anhydrides and were 8.39, 7.44 and 6.47 Debye units, respectively. These dipole moments agreed well with their gc retention times which have been shown to increase with increase in dipole moments for different isomers (Duty, 1977).

These oxidations were carried out on a 10g. sample of solvent refined lignite that had been extracted into a benzene-methanol reflux as previously described (Duty, 1980). The solvent from the benzene/methanol was removed, and the residue was refluxed for 1-2 h with approximately 100 ml of acetic anhydride. The solution was evaporated to dryness, and the residue was dissolved in methylene chloride for GC-MS analysis. The oxidation was carried out at 250° for 72 h with limited dichromate (55.lg $Na_2Cr_2O_7$ H_2O, 500 ml H_2O, 5g. NaH_2 PO_4 H_2O) and analyzed as previously described (Duty, 1980).

RESULTS AND DISCUSSION

In the previous study (Duty, 1980), we had identified naphthalene dicarboxylic acids as one of the most abundant acids produced in the oxidation of the solvent refined lignite. In that study it was apparent from the gas chromatographic traces that the methyl esters of the naphthalene dicarboxylic acids were eluting as only three peaks.

There are 10 isomers for the dicarboxylic acid of naphthalene, and only 3 of

these isomers would form cyclic anhydrides; the 1,8, the 1,2 and 2,3 dibasic acids (See Figure 1).

Since the limited dichromate oxidation of SRL produced three naphthalene dibasic acids, the acids from these oxidation reactions were converted to anhydrides by refluxing with acetic anhydride to ascertain if any of these three cyclic anhydrides were present. The results of these anhydride experiments are given in Table I.

The most abundant cyclic anhydride was phthalic anhydride and all of these naphthalene anhydrides have been normalized to phthalic anhydride which was chosen as 100. The interesting feature in Table I is the appearance of all three cyclic anhydrides of naphthalene. The other 7 isomers of naphthalene evidently are not produced or produced in such low percentages that they are not detected by the GC-Mass spectrometer.

These three dibasic acids of naphthalene suggest that the polynuclear aromatic and/or hydroaromatic repeating units in solvent refined lignite extend from the 1,2 position in naphthalene as frequently as they do from the 2,3 position, i.e., a phenanthrene-type repeating unit and/or an anthracene-type repeating unit (See Figure 2).

In addition, since the 1,8-cyclic anhydride represented only about 6-7% of the concentration as the other two cyclic anhydrides, one can conclude that the repeating units which branch off from the 1,8 position of naphthalene are very few compared to the 1,2 and 2,3 positions.

ACKNOWLEDGEMENTS

The author is greatful for a faculty research appointment at the Argonne National Laboratory funded by the Department of Energy, and wishes to express his thanks to R. Hayatsu and R.E. Winans for their helpful discussions.

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Table 1. Relative Abundances of Cyclic Anhydrides (SRL-Benzene/MeOH extract-limited $Na_2Cr_2O_7$ oxidation)

Anhydrides	SRL
Phthalic anhydride	100
2,3-naphthalic anhydride	10
1,2-naphthalic anhydride	9.0
1,8-naphthalic anhydride	0.64

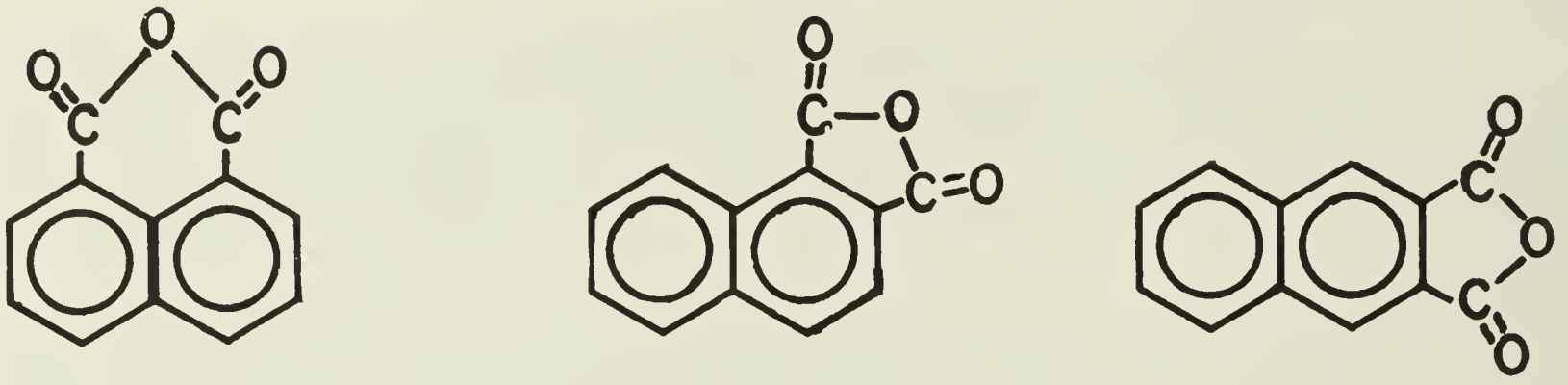
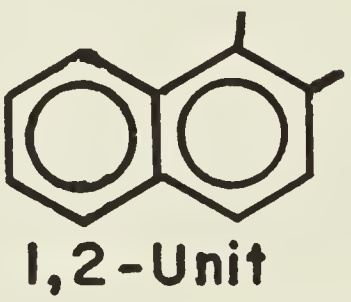
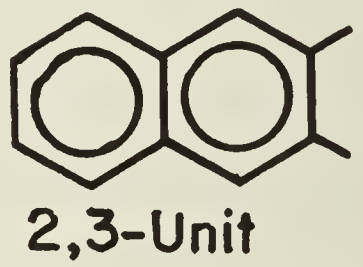


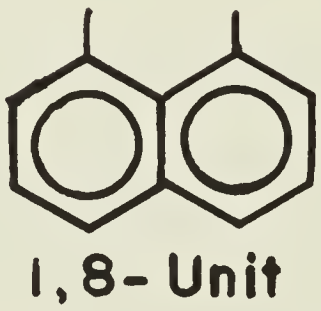
Fig. 1



1,2-Unit



2,3-Unit



1,8-Unit

Fig. 2

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LOBELIA CARDINALIS X L. SIPHILITICA IN ILLINOIS

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ABSTRACT

A population of *Lobelia cardinalis* X *L. siphilitica* was recently found growing in Coles County, Illinois. The members of this population are intermediate in their characteristics between the two parent species. Though no pollen is produced in the hybrids, some seed set was observed. These seeds proved to be viable, and produced individuals which are intermediate between the F_1 hybrids and *L. siphilitica*.

The hybrid between *Lobelia cardinalia* L. and *L. siphilitica* L. was first described by Schneck (1876), who discovered a few individuals in a low, moist woods in Wabash County, Illinois. He mentioned that these individuals are nearly as pubescent as those of *L. siphilitica*, have flowers with slender tubes and the aspect of *L. cardinalis*, but the flowers are broader at the mouth and have more conspicuous folds in the throat. These hybrids also have the reflexed calyx sinuses of *L. siphilitica*, but they are very short. He further mentions that the bracts are intermediate, as is the flower color, which is deep reddish or crimson-purple. Schnecks' specimen was examined by Gray (1876) who considered it of hybrid origin. The only other Illinois report of this hybrid is by Robertson (1928) who found it growing within 10 miles of Carlinville, Macoupin County, Illinois.

Recently a hybrid population consisting of five individuals was found about 1 mile northwest of Hutton, Coles County, Illinois. These individuals were growing in a disturbed, grassy area near a large pond, close to a population of *Lobelia siphilitica*. *Lobelia cardinalis* does not presently occur at this site, though a few populations have been found within one mile of the area.

Lobelia cardinalis and *L. siphilitica* are similar in their vegetative characteristics. Both are coarse perennials with usually simple stems to 1.5 m tall. Their leaves are lanceolate to narrowly ovate with irregularly serrate margins. In *L. siphilitica* the stem is usually sparsely hisute on the angles while in *L. cardinalis* the stem is usually glabrous, though occasionally individuals are found with puberulent stems. Also,

most of the specimens of *L. siphilitica* examined have leaves that are hirsute on the veins beneath and usually strigose above, while in *L. cardinalis* the leaves are usually glabrous.

Though similar in their vegetative characteristics, the two species are strikingly different in their floral and inflorescence characteristics (Table 1). In *L. cardinalis* the bracts are relatively small and glabrous, the sepals are long and narrow and lack auricles, while the corolla lobes are bright red, relatively long and narrow, and usually glabrous. *Lobelia siphilitica,* in contrast, has much larger bracts, the sepals are relatively short and broad with well developed basal auricles, while the light blue corolla lobes are relatively short, broad, and hirsute. As can be seen from Table 1, the F_1 hybrid of these two species is intermediate in most of these characteristics. This is particularly true in the size of the bracts, the sepal width, the size of the basal auricals, and the length and width of the corolla lobes.

In all of the hybrids examined no pollen was produced, and in most cases the anthers aborted and did not develop. However, some seeds were produced in the developed capsules. In ten fruits examined there was an average of 62.7 seeds (ranged from 27 to 104) per capsule. These seeds were well formed and when planted about 75% germinated. All of the individuals produced were intermediate between the original F_1 and *Lobelia siphilitica*. These individuals also did not produce viable pollen, but did produce some seeds when crossed with *L. siphilitica*.

Specimens examined:

Coles County: Open, grassy area near Hunt's pond, 1 mile NW of Hutton, IL (Sec 9 T11N R10E), J.E. Ebinger 19879, 22 August 1980 (EIU); J.E. Ebinger 20401, 12 October 1980 (EIU); J.E. Ebinger 20832, 24 September 1981 (EIU, ISM).

Cass County: River bottom, NW part of county, R.T. Rexroat 10473, 20 August 1967 (ISM).

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Table 1. Flower, pedicel, and bract characteristics of *Lobelia cardinalis*, *L. siphilitica*, and their hybrids. Measurements and observations were made on 20 mature flowers from the five hybrid specimens, and from randomly selected individuals in populations of the species. For all measurements (mm) the maximum and minimum is given while the averages are shown in parentheses.

Character	*L. cardinalis*	*L. cardinalis* X *L. siphilitica*	*L. siphilitica*
Bract — length	12.5-24.5 (17.6)	18.6-25.0 (21.7)	21.0-38.0 (27.2)
— width	1.1-2.6 (1.7)	3.5-6.6 (4.8)	5.9-14.0 (8.9)
— pubescence	glabrous	glabrous	hirsute
Gland position on pedicel	basal	medial	apex
Pedicel — length	4.2-9.1 (6.9)	6.0-9.5 (7.9)	4.0-8.0 (5.0)
— pubescence	puberulent	hirsute	hirsute
Sepals — length	12.6-16.0 (14.3)	14.0-17.5 (15.5)	9.7-13.6 (11.6)
— width	1.0-1.4 (1.2)	3.5-4.8 (4.0)	3.2-7.2 (5.0)
— pubescence	glabrous	hirsute	hirsute
Auricles — length	absent	0.6-1.2 (.8)	.8-4.0 (2.9)
Upper corolla lobes — length	16.0-20.0 (17.7)	12.0-16.5 (14.9)	9.3-15.1 (11.8)
— width	0.9-1.4 (1.1)	1.6-2.0 (1.8)	2.4-5.4 (3.3)
— pubescence	glabrous	hirsute	hirsute
Lower mediam corolla lobes — length	13.2-19.0 (15.4)	11.5-17.2 (13.3)	4.3-11.6 (7.7)
— width	2.0-3.5 (2.7)	3.2-4.2 (3.6)	2.6-5.5 (4.0)
— pubescence	glabrous	hirsute	hirsute

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STRATIGRAPHY AND DEPOSITIONAL HISTORY OF THE PENNSYLVANIAN SEQUENCE EXPOSED AT THE CAGLE'S MILL SPILLWAY PUTNAM COUNTY, INDIANA

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ABSTRACT

The Early Pennsylvanian Mansfield Formation outcrop at the Cagle's Mill spillway cut is an extensive and complex display of interbedded sandstone and shale bodies. Two episodes of deltaic progradation into a shallow water body are recorded in these rocks. An orbiculoid brachiopod in the lowermost unit indicates progradation of the first delta into a shallow marine environment.

Delta front and delta plain depositional environments, much modified by fluvial processes, dominate the Cagle's Mill rocks. Several types of fluvial sedimentation include cut and fill by lateral migration, channel fill by vertical accretion and deposition by crevasse splay.

INTRODUCTION

The Cagle's Mill spillway, section 13, T. 12N, R. 5W, southern Putnam County, Indiana is described in reconaissance fashion by Langenheim *et al.* (1966). The purpose of this project is to define in detail the major stratigraphic units, their sedimentary structures and petrology as well as to propose an environmental interpretation of the complex.

MATERIALS AND METHODS

Approximately 6 days were spent in the field during October and November, 1982. Major stratigraphic units were defined and their relationships documented. Also, specimens were collected for thin sectioning and petrographic study. Several of the shale and mudrock units, however, were not thin sectioned because of their fissile or unconsolidated nature.

RESULTS AND DISCUSSION

General Geologic Setting

The Cagle's Mill spillway cut exposes the Early Pennsylvanian Mansfield Formation and overlying Kansan and Illinoisan till (Langenheim *et al.* 1966). In this area the Mansfield Formation unconformably overlies the Middle Mississippian Ste. Genevieve Limestone, which is exposed at the outlet tunnel of the Cagle's Mill dam.

General Geology of the Spillway

Major rock types exposed are fine-grained quartz arenite and fine-grained lithic quartz arenite, both with interbedded shale layers. Carbonaceous quartz arenite is abundant. Shale and coal are minor constituents in the cut but a thick shale sequence crops out along the road north of the spillway.

Virtually all units exposed in the cut are truncated by one or more erosion surface (figs. 1, 2) precluding definitive measurement. Therefore, approximate thicknesses only are reported where appropriate.

Individual rock units of distinctive environmental significance are designated by number (figs. 1, 2).

Stratigraphy and Depositional Environments

Units 1a, 1b, 1c and 1d

The basal unit exposed in the spillway is approximately 27 feet of shale and silty shale. This sequence is divided into 4 units; 1a, 1b, 1c and 1d based on macroscopic lithologic character. These units are too friable for thin sectioning but a thin section of a siderite concretion occurring in unit 1a is available.

Unit 1a, the lowermost rock exposed in the area, is very poorly exposed and its character is inferred mainly from talus samples. The unit consists of approximately ten feet of dark gray, carbonaceous, silty, quartzose shale. Rounded siderite concretions are not uncommon. Petrographic analysis of a concretion indicates moderate bioturbation. Angular quartz silt comprises as much as 35% of the concretion. One orbiculoid brachiopod (fig. 3) was found in this unit. Unit 1a is conformably overlain by unit 1b.

Unit 1b consists of approximately 10 feet of gray to light gray, poorly bedded to massive, silty mudstone. Absence of fissility and poor bedding are attributed to bioturbation. This unit is conformably overlain by unit 1c.

Unit 1c consists of approximately 6 feet of very dark gray to black, organic, silty shale with sandy layers and lenses and several thin interbeds of gray mudstone resembling unit 1b. Bioturbation is rarely apparent. Lenticular and rounded siderite concretions stained with iron oxides are also present. *Cordaites* leaves and *Calamites* branches are abundant, especially near the top of this unit. Unit 1c is unconformably overlain by unit 2a which fills a channel cut into unit 1c. The lithologic character of unit 1c apparently undergoes a substantial change eastward where it abruptly changes into unit 1d. However, the nature of this relationship is not certain because

the contact is obscured. Thus it is also possible that the contact may be somewhat gradational.

Unit 1d is best exposed immediately east of the lowermost eastern channel fill of unit 3 exposed on the north wall of the cut (fig. 2). It consists of moderately to poorly bedded, light gray mudstone and shale interbedded wavy laminae of sand, wedges of sandstone and some thin but apparently continuous beds of sandstone. All of the sandstone is fine- to very fine-grained. Plant fossils and carbonaceous rocks are abundant throughout.

Mudstone, sandstone stringers and abundant plant fossils indicate that this unit may be a variation of unit 1c. The poorly bedded gray mudstone of unit 1d differs substantially from the fissile, carbonaceous shale of 1c and the change occurs over an exceptionally short distance indicating an unconformable contact. Unit 1d is unconformably overlain by units 4a, 3 and possibly by unit 2a, the 2a-1d contact is unexposed.

Depositional Environment of Units 1a, 1b, 1c and 1d

The predominance of clay and silt particles and general fissility of these units suggest deposition in a very low velocity environment. The sandstone stringers indicate occasional increased competence. These characters, as well as the lack of animal fossils, presence of plant fossils and presence of sideritic concretions fits Wanless *et al.'s* (1970, p. 220-221) description of Pennsylvanian delta front muds very well. Bioturbation of delta front muds is well documented by Coleman (1976, p. 29-30). Lack of extreme bioturbation in most of these shales is attributed to low oxygen to anoxic conditions caused by the oxidation of the abundant plant material. This made the area unsuitable for burrowing organisms. Prominant bioturbation in unit 1b suggests that the poor oxygen conditions were replaced temporarily by more "normal" conditions. The change in oxygen concentration could be caused by a change in water chemistry, intermittent failure of a barrier to free circulation or a decrease in the amount of organic matter. The thin bioturbated and/or light gray layers within the dark gray shale of unit 1c indicate an abrupt change for a short period of time. Decrease in organic influx seems the most logical cause of this change.

The thickness of unit 1b implies a longer period of deposition without abundant organic material. This layer is approximately 10 feet thick and could conceivably be deposited in 15 to 20 years (Coleman, 1970, p. 48-49) assuming a compaction-dewatering ratio of 2:1. A decrease in organic matter for that period of time appears to be a more feasible explanation than a longer, more dramatic change such as the temporary opening of a restricted bay to open circulation.

Units 2a and 2b

Unit 2a unconformably overlies unit 1c and possibly unit 1d. It consists of 2 feet of massive, dark to very dark gray, well cemented, fine-grained sandstone with iron sulfate deposits on weathered surfaces. This fine-grained quartz arenite consists of 85% well sorted, subangular quartz, approximately 5% schist and phyllite grains and 5-8% clay minerals (fig. 4). Accessories, including metaquartzite, zircon, chert, microcline and tourmaline comprise 1-2% of the rock. Two episodes of cementation are evident; the first deposited syntaxial quartz overgrowths on the quartz grains and the second filled pores with iron pyrite. Unit 2a fines upward and grades into unit 2b.

Unit 2b is laminated and burrowed, quartzitic and lithic, carbonaceous shale. This unit is 6 inches thick where exposed but it is unconformably overlain by unit

3 and the true thickness is unknown. It consists of 40% fine-grained, angular quartz sand and quartz silt, 25% detrital clay minerals, 25% organic matter with secondary pyrite and 5-7% silty shale intraclasts (fig. 5). Much of the quartz sand is concentrated in burrow fillings. Accessories present include schist and phyllite, potassium feldspar, microcline, tourmaline, siltstone, muscovite and metaquartzite.

There are 3 mineralogically distinct types of internal laminae. These laminae average .5-1mm thick and each type is responsible for about one-third the total rock volume. The first type is dominantly carbonaceous matter with shale intraclasts; fine-grained quartz sand and clay minerals being much less abundant. The second type of laminae is mostly fine-grained quartz sand in a clay matrix with very little carbonaceous matter. The third type contains quartz sand, clay minerals and carbonaceous matter in about equal proportions. These laminae are irregular and discontinuous. Unit 2b is unconformably overlain by unit 3.

Environment of Deposition of units 2a and 2b

Units 2a and 2b are considered flood deposits on the delta front. The erosional base and massive sandstone at the base were produced by a short term rapid change in depositional conditions caused by an increase in flow velocity. The numerous shale intraclasts in unit 2b indicate active erosion of a mud substrate which is also indicative of increased flow velocities. As the flood waned, velocity decreased and the finer-grained, laminated material of unit 2b was deposited.

Layers 2a and 2b very closely resemble the A and B layers of a Bouma sequence (Blatt *et al.*, 1980, p. 145; Bouma, 1962, p. 48-54) which also is formed by a relatively large, short-lived sediment influx with decreasing flow regimes. Bed 2a appears equivalent to Bouma's A unit (1962) consisting of a graded, thick bed of the coarsest available sediment, here fine-grained sand. Bed 2b is similar to the B layer consisting of hydrodynamically lighter materials deposited in the planar phase of the upper flow regime as laminae. The C, D and E layers should be present if flow velocities decreased to relatively still water. Units 2a and 2b however, are truncated by an unconformity and these beds may have been removed by erosion.

Unit 3

Unit 3 unconformably overlies units 1c, 1d, 2a and 2b and consists primarily of cross bedded, lenticularly and planarly bedded fine- and very-fine grained, lithic quartz arenite with quartz and hematite cement. Silty shale and mudstone partings are not uncommon in this unit. Unit 3 is composed of repeated sequences representing repeated depositional events. Most sequences, however, are incomplete because of cut and fill processes.

The mineralogy of the lithic quartz arenites is virtually the same throughout the unit although proportions of the various constituents change somewhat from bed to bed. Grains of subangular, fine to very fine-grained quartz sand make up 60-80% of the rock. In some rocks the quartz grains are oriented with their long axis parallel to bedding, giving the rock a microbedded to micro-imbricated texture. Metamorphic rock fragments of schist and phyllite, generally larger than associated quartz grains are second in abundance. They constitute 10-15% of the rock in most cases but range from 2-20%. In some layers the metamorphic rock fragments are very abundant and compacted thus forming a pseudomatrix in which the quartz grains may float. Carbonaceous matter in these rocks is concentrated on bedding planes and ranges from 0-4%. Accessories in unit 3 include zircon,

microcline, plagioclase, tourmaline, chert, potassium feldspar, metaquartzite and muscovite. Muscovite composes as much as 1% in a few of the samples.

Rocks in unit 3 exhibit 2 episodes of cementation. The first produced syntaxial quartz overgrowth on the quartz grains. This overgrowth appears a result of pressure solution processes as indicated by the widespread concavo-convex quartz grain contacts. Quartz cement is less well developed in rocks containing abundant metamorphic rock fragments. The second cementation filled virtually all pores with hematite cement. Much, if not all, of this cement may be derived from the alteration of schist and phyllite grains to hematite and sericite. This also may explain some of the difference in metamorphic rock content from bed to bed.

Although the mineralogy of the lithic quartz arenite is relatively uniform throughout the unit, grain size is bimodal and directly proportional to bed thickness. The thick-bedded sandstones are usually over 8 inches in thickness and contain grains 3 to 4 times as large as those of the more thinly bedded sandstone. There apparently is no gradation between the coarser-grained and finer-grained sandstone and the two probably represent a tractional and suspended sediment load (figs. 6, 7).

The sequential ordering of sedimentation in this unit is best viewed 15 to 20 feet west of the lowest resistant sandstone within the unit. This is approximately in the middle of the north side of the cut (fig. 8).

Each sequence rests on an erosional base. The lowermost subunit is cross bedded sandstone, that is as much as 5 feet thick, and may contain intraclasts. Dislodged pieces of this unit also have current ripples and trackways on bedding planes. This lower subunit grades into a thinly to lenticularly bedded sandstone subunit that ranges from a few inches to a foot in thickness. It is at this level that the dramatic decrease in grain size occurs. This second subunit grades into a thin, discontinuously planar bedded sandstone subunit with micro-cross laminae. Beds within this subunit do not persist horizontally for great distances. The planar bedded sandstone in turn grades into a light gray, silty shale subunit which generally is a few inches thick. Only the basal beds are present in most of unit 3 and they cut into one another giving the rock a lenticularly bedded appearance. The upper third of unit 3 is distinctly thin bedded, exhibits planar bedding and contains some shale partings. Unit 3 is unconformably overlain by units 4a, 4b and 4c.

Depostional Environment of Unit 3

Unit 3 is interpreted as a series of superposed point bar sequences deposited by a meandering stream, probably a deltaic distributary. This interpretation is based upon the prevalence of the immature, angular arenite with large percentages of metomorphic rock fragments (Potter, 1967, p. 344) and the repeated sedimentary sequences within this unit. These properties also occur in the meandering fluvial sand bodies described by Klein (1980, p. 26-27), Blatt *et al.* (1980, p. 636-639) and Reineck and Singh (1980, p. 267-274). Inference of a meandering nature of the stream is supported by paleocurrent data (fig. 9) indicating that the current direction differed as much as 90 degrees from a generally south southwestern direction. The most apparent digression from the descriptions of these authors is the lack of a lag deposit at the base of each depositional sequence. I attribute this to the deposition in a deltaic distributary as the coarser material would have been deposited far upstream. Several large intraclasts observed in this unit may be the counterpart of a lag deposit in this environment (fig. 10).

Units 4a, 4b, 4c, 4e and 4f

Unit 4a is the lowest of 5 units filling the major channel exposed in the cut. It consists of approximately 2 to 2.5 feet of fine-grained, angular quartz arenite with carbonaceous matter and metamorphic rock fragments. The upper part of this unit contains some interbedded silty gray shale. This sandstone is much "cleaner" than the sandstone in unit 3 with fine-grained quartz sand comprising 95% of the grains present. Three percent of the rock is grains of schist and phyllite and about 1% of the rock is carbonaceous material. Accessories present are zircon, tourmaline, muscovite, plagioclase, potassium feldspar and chert. The rock is pressure welded and cemented by incomplete quartz overgrowths. Sand sized grains of diagenetic iron pyrite are abundant throughout.

Unit 4a is limited to the channel floor and is poorly exposed. It is overlain by unit 4b in abruptly gradational contact.

Unit 4b consists of 4-8 inches of laminated silty gray shale. Unit 4b has an abruptly gradational contact with unit 4c.

Unit 4c consists of 6-8 inches of silty, carbonaceous black shale with coaly lenses. Unit 4c is the lowest channel filling unit to extend across the entire width of the channel. This unit has a rapidly gradational contact with unit 4d.

Unit 4d consists of as much as 2 feet of poor quality coal. The coal is mostly fusain and durain, vitrain being a minor constituent. The coal covers the entire channel floor being thickest at the bottom of the channel and thinning noticeably on the flanks. It is possible that the peat which formed this coal may have filled this channel in which case a constant channel depth/coal thickness ratio could be expected across the channel if peat compaction was uniform across the channel. Angular measurements taken to obtain these values give ratios of .062-.125, the average being .09. Channel depth/coal thickness ratios from measurements taken from photographs of the cut yield ratios of .06 to .11. The largest values are at the bottom of the channel and there is a systematic and uniform decrease toward the western flank. This suggests that approximately one-third more peat accumulated in the central part of the channel than on the outer edge. This effect could have been caused by compaction of the peat in the deeper part of the channel during peat accumulation allowing a greater volume of peat to fill the central part of the channel. Continuing subsidence within the channel with the greatest compaction in the midportion is also evidenced by downward bowing of the bedding in unit 4f (figs. 1, 2). Unit 4d is conformably overlain by unit 4e and unconformably by unit 5a.

Unit 4e consists of approximately 4 inches of black, fissile, silty, quartzose, carbonaceous shale. The weathered surface is bright orange and rosettes of gypsum crystals 1/4 inch in diameter occur on bedding planes. This unit is thickest at the center of the channel but thins somewhat on the flanks. This unit contained the only other invertebrate fossil noted in the entire complex, a small pelecypod poorly preserved as a carbonaceous film on a bedding plane.

The mineralogy of this rock (fig. 11) consists of 35% fine-grained sand and silt sized quartz grains all with their long axis parallel to bedding. Most of the quartz floats in a matrix of carbonaceous materials and clay which make up the remaining 65% of the rock. Some of the quartz, however, is concentrated in thin, lenticular laminae.

Unit 4e is conformably overlain by unit 4f and truncated laterally by unit 5a.

Unit 4f, the major channel filling unit in the cut, is a thin bedded (.15-.50 inch), silty, carbonaceous, gray, fine-grained quartz arenite. Beds are continuous and bow

downward from the flanks of the channel into the center (fig. 2). Flaser bedding and microcross laminae occur in some of the beds.

Unit 4f consists of 80% subangular fine sand sized to silt sized quartz which is moderately well sorted (fig. 12). Carbonaceous material comprises 10-15% of the rock and detrital clay minerals account for 5-10%. Some of the specimens contain notable percentages of shale and metamorphic rock fragments. Accessories present include tourmaline, zircon, plagioclase, microcline, chert and muscovite. The rock has been bioturbated and rare shell fragments were noted in one thin section.

The rock has undergone 2 episodes of cementation. The first yielded a poorly-developed syntaxial quartz overgrowth cement. The second introduced a rare, void filling, hematite cement. Diagenetic pyrite is abundant in some specimens.

Unit 4f is unconformably overlain by units 5a and 7.

Environment of Deposition of Units 4a-4f

Units 4a and 4b are interpreted as the final depositional sequence in an abruptly abandoned stream course, as suggested by their thinness and fining upward character. The near proximity of deltaic deposits (Pryor and Sable, 1974), lack of coarse load and abundant organic matter suggest that this channel may have been a distributary eroding older deltaic sediments.

Upon channel abandonment and loss of competence the coarse load, represented by unit 4a was deposited in mid channel as this would be where the highest velocities and coarsest load would be located. The deposition of finer grained suspended materials, now comprising unit 4b, followed as current velocities decreased to zero.

Unit 4c represents the transition to suspension deposition in a stagnant environment. Here detrital material becomes less and less available in contrast to increasing organic accumulation leading eventually to peat accumulation. The very fine-grain, areal extent across the channel, fissility and organic rich composition indicate deposition from suspension under quiet, reducing conditions within the channel. As the stream was no longer active at this time the material was brought in during periods of high water on the deltaic plain. These deposits characteristically are composed of silty clay with much organic debris (Coleman, 1976, p. 35-36).

Unit 4e is interpreted as an allochthonous coal deposited in the channel as a channel filling peat. Coleman (1976, p. 36) states that the late stages of channel filling normally are characterized by a high abundance of peat. There is no indication of soil formation, root burrows or exposure features at Cagle's Mill which would suggest water shallow enough to allow peat accumulation in a marsh.

Unit 4e is transitional between peat accumulation and the deposition of the more siliciclastic unit 4f. Carbonaceous matter is still abundant, composing 65% of the rock, but the clay and quartz content increases. This is interpreted as being caused by a source of terrigenous clastics encroaching close enough to affect the composition of the sediment deposited during periods of high water.

The thinly bedded unit 4f appears to be mainly overbank deposits very strongly influenced by the nearing source of clastics alternating with suspension deposition during low water periods. Some of the thin, continuous beds are lenticular to flaser bedded which, according to Reineck and Singh (1980,, p. 113), form where both mud and sand are available for deposition and periods of deposition alternate with periods of quiesence. These beds sag towards the middle of the channel indicating that the peat in the channel was compacting during the deposition of unit 4f.

Periods of still water alternating with increased flow velocities were common-

place during the deposition of unit 4f as indicated by thin, continuous beds of very fine-grained sandstone alternating with persistent layers of mud and carbonaceous matter (fig. 13). Thinly bedded clay and silt channel fill deposits also are reported from the Brazos River, Texas, by Bernard and Major (1963).

Units 5a and 5b

Unit 5a, unconformably succeeding units 4c, 4d, 4e and 4f is a poorly to lenticularly bedded, gray, fine-grained, lithic, quartz arenite. This unit contains abundant *Calamites* branches and logs and carbonaceous imprints of *Cordaites* leaves. The composition of this rock differs little from that of unit 3, consisting primarily of poorly sorted, medium-, fine-, and very fine-grained subangular quartz grains. Metamorphic rock fragments are moderately abundant. The rock is cemented by secondary quartz and hematite. This unit is laterally discontinuous and generally fills troughs cut into unit 4f. This unit grades vertically into unit 5b.

Unit 5b is thinly bedded, with beds up to 8 inches thick, and is a medium- to fine-grained, red to brown, lithic, quartz arenite. Many layers are micro-cross laminated with carbonaceous films on the bedding planes. The upper bounding bedding planes have complex interference ripples (fig. 14). Beds in this unit are of strikingly constant thickness and persist laterally for 50-75 feet before pinching out. These rocks are mineralogically identical to unit 3 but are finer-grained, moderately well sorted and have a slight fining upward trend in the upper part of the unit.

Environment of Deposistion of units 5a and 5b

The basal sandstone (unit 5a) containing coarse material grading into fine material with abundant plant fossils and resting on a scoured base is like the sequence forming the basal portions of the fluvial sequences described in unit 3. The lack of sedimentary structures within the lower portion indicates rapid dumping rather than systematic deposition in dunes and bars as in unit 3 (Reineck and Singh, 1980, p. 130). The good sorting, fining upward trend, micro-cross laminae and uniform bedding of unit 5b indicate deposition under less severe conditions with decreasing velocity. Complex interference ripples are interpreted by Picard and High (1973, p. 88) as recording changing hydraulic conditions as a flood recedes. Thus units 5a and 5b appear to result from rapid sediment influx and dumping under relatively high conditions followed by systematic velocity decrease producing evenly bedded, fining upward sediments. These units probably represent a small crevasse splay that had a rapid surge of water which transported coarse material. Then, velocity decreased, the flood waned and the crevasse was repaired. Crevasse deposits are described as "fine-grained sandstone, flat bedded or with micro-cross laminations containing sufficient vegetable detritus. . . to impart a dark gray color to certain bedding planes." ". . . more extensive and less variable than channel type sands." by Wanless *et al.* (1970, p. 221). These sandstones at the Cagle's Mill cut are virtually identical to those described in this (notably brief) description.

Units 6a, 6b and 6c

Unit 5b abruptly grades into unit 6a. A 2 inch thick sandy layer marks the contact and, inasmuch as unit 6a is predominantly gray shale, it is likely that this is reworked material. Thus the two units do not represent continuous deposition.

Unit 6a consists of 6 feet of silty, fissile, gray shale with very fine-grained sandstone and siltstone lenses and layers 1/64 to one inch thick. The finer-grained lenses are much more abundant. Lenticular sideritic concretions are widespread. Petrographic analysis of one of these concretions reveals layers of coarse grained mate-

rial, mostly angular, fine-grained sand and silt sized quartz, some oriented parallel to bedding, metamorphic rock fragments and planar bedded muscovite alternating with layers of clay-sized material with sparse angular quartz silt. These layers are planar bedded.

Bioturbation derived round siderite concretions are 1/8-1/4 inch in diameter. Unit 6a gradually grades into unit 6b.

Unit 6b is 3 feet of fine-grained, white, lithic, subangular quartz arenite. Beds are up to 2 inches in thickness. The sandstone is approximately of the same composition as that of unit 3, differing mainly in the lack of hematite cement. The sandstone is interbedded with thin-bedded sandstone.

The sandstone is micro-cross laminated. Burrowing has produced rounded iron stained masses 1/8-1/4 inch in diameter. Unit 6b grades into unit 6c.

Unit 6c is 6 inches of fine-grained, white, quartz arenite with a clay mineral matrix. The unit is heavily bioturbated on its upper surface (fig. 15) and lacks internal structure. It is composed of 85% fine-grained sand to silt-sized subangular quartz. Much of this quartz floats in a detrital clay mineral matrix comprising about 10% of the rock. Schist fragments constitute about 2% of the rock. Accessories include plagioclase, chert, metaquartzite, zircon, muscovite and potassium feldspar. Unit 6c is the uppermost Pennsylvanian unit exposed in the area and is unconformably overlain by unit 7, a Pleistocene till.

Environment of Deposition of Units 6a, 6b and 6c

The fine-grained detrital coarsening upward sequence of unit 6 is inferred to be deposited by a thin, prograding deltaic lobe. The total thickness of unit 6 is only 10 feet but many of the coarsening upward Pennsylvanian deltaic sequences are notably thin because they were deposited in a shallow cratonic sea (Klein, 1980, p. 107-108; Wanless *et al.*, 1970, p. 224). The gradation from shale to sandstone represents transition from distal deltaic deposits to sediments deposited near the distributary mouth. The distributary depositing sands into the area need not have been extremely near by. The sediments carried by these rivers may merge laterally into one another forming thin sheet sands near the front of the deltaic lobe (Coleman, 1976, p. 14). This may explain the lack of an erosional basal contact as observed below in unit 3.

Units 7 and 8

Units 7 and 8 are Pleistocene loess and till deposits separated by a paleosol between them. These units are not described here but have been described in detail by Wayne (1958, p. 10).

CONCLUSIONS

Depositional History of the Pennsylvania Sequence Exposed at the Cagle's Mill Spillway

The lowest rocks exposed in this sequence were deposited as muds and silts falling out of suspension at the front of a delta prograding into a shallow marine environment. Organic content of the sediments generally remained high but upon occasion were depleted, allowing increased biologic activity in the sediments. Rare, exceptionally high velocity surges of the delta front scoured the bottom and brought relatively coarse material into the area, such as the sediments composing the rocks of units 2a and 2b.

Shallow cratonic seas are characteristic environments of the Pennsylvanian

eastern midcontinent (Blatt *et al.*, 1980, p. 688; Wanless *et al.*, 1970, p. 239; Pryor and Sable, 1974, p. 313) and it is likely that these sediments accumulated in such a sea. Distal deltaic deposits in shallow environments build up above the level of the bottom of distributaries delivering the sediment. This causes unconformable contact at the base of prograding distributary sediments (Donaldson *et al.*, 1970, p. 107; p. 116). Progradation of an extensive generally south flowing, distributary system, cut into the earlier distal muds delivering the sand now observed as unit 3. These abundant sand deposits were deposited on a deltaic plain (Wanless *et al.*, 1970, p. 224).

Channel avulsion or lobe abandonment caused desertion of the principal channel observed in the Cagle's Mill spillway. The tractional load being carried was deposited immediately as unit 4a followed by deposition of the suspended load, unit 4b, in still, oxygenated water. Furthur suspension deposition under increasingly stagnant conditions produced the black shale of unit 4c. With the deprivation of any active source of clastics little detritus was available to fill the channel except for transported organic debris (Coleman, 1976, p. 35) which filled the channel with peat. The peat, constantly compacting under its own weight, provided a low area where sedimentation continued.

The approach of a new source of clastic material on the delta plain, possibly caused by lobe reactivation or more probably a new channel entering the area, produced unit 4e in which the carbonaceous material is diluted with clay minerals and quartz grains. Furthur encroachment of the new clastic source increased the supply of sediment available for channel filling by overbank flow. This increasingly coarse material filled the depression formed by the peat compaction in the old channel. The final channel fill, unit 4f, is composed of overbank deposits alternating with suspension deposits. Accumulation probably also occurred on adjoining areas during periods of flooding.

After the channel was filled rapidly and completely by these processes there was little compaction as bedding in other overlying sediments does not sag in the channel region.

Thereafter crevassing onto the delta plain, possibly from the same nearing distributary system supplying the channel fill laid down units 5a and 5b.

Rapid subsidence allowed the area to become submerged quickly with a minimum of reworking of the upper beds. Thereafter a small delta or subdelta prograded into the newly formed bay, producing the coarsening upward sequence of units 6a, 6b and 6c. Absence of a unit consisting primarily of shale or clay indicates that this area was not far removed from a sediment source. The gradational nature of this deposit as well as the abundant clay material in the uppermost sandstone indicates that the spillway area was near but not immediately in front of a prograding distributary. Being distal to the prograding bar this environment would probably be best described as the bar front of Klein (1980, p. 101). Sediments deposited in this environment consist of sand and silt dispersed from the mouth of an active distributary.

In summary the following sequence of environments is represented at the Cagle's Mill spillway.

1. Delta front
2. Delta Plain-fluvial distributary
3. Delta Plain-flood deposition
4. Shaly Prodelta
5. Sandy and Silty Delta front
6. Sandy Bar Front

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Figure Captions

Fig. 1. Schematic representation of stratigraphy and lithologies on the north wall of the spillway. Numbers correspond to those in text.

Fig. 2. Exposure of Pennsylvanian sequence on the north wall of the spillway. Numbers correspond to numbering scheme of figure 1 and in text.

Plate 3.

Fig. 3. orbiculoid brachiopod collected from unit 1a, x8, bar scale equals 5mm.

Fig. 4. unit 2a, x80, uncrossed polars, bar scale equals .5mm.

Fig. 5. unit 2b, x80, uncrossed polars, bar scale equals .5mm. Note laminated appearance, shale intraclast.

Figs. 6, 7. Unit 3, thick bedded (6) and thin bedded (7) subunits, x80, crossed polars, bar scale equals .5mm. Note difference in size and high degree of sorting.

Fig. 8. depositional sequence, unit 3. The lowermost unit is approximately 5 feet thick.

Fig. 9. paleocurrent data, unit 3. single dots are poles to crossbeds, double headed arrow is current ripple trend and single headed arrows are indicated paleocurrent direction.

Plate 4.

Fig. 10. intraclast in lower subunit of unit 3. Intraclast is approximately 7.5cm in diameter.

Fig. 11. unit 4e, x20, uncrossed polars, bar scale equals .5mm.

Fig. 12. unit 4f, x20, uncrossed polars, bar scale equals .5mm.

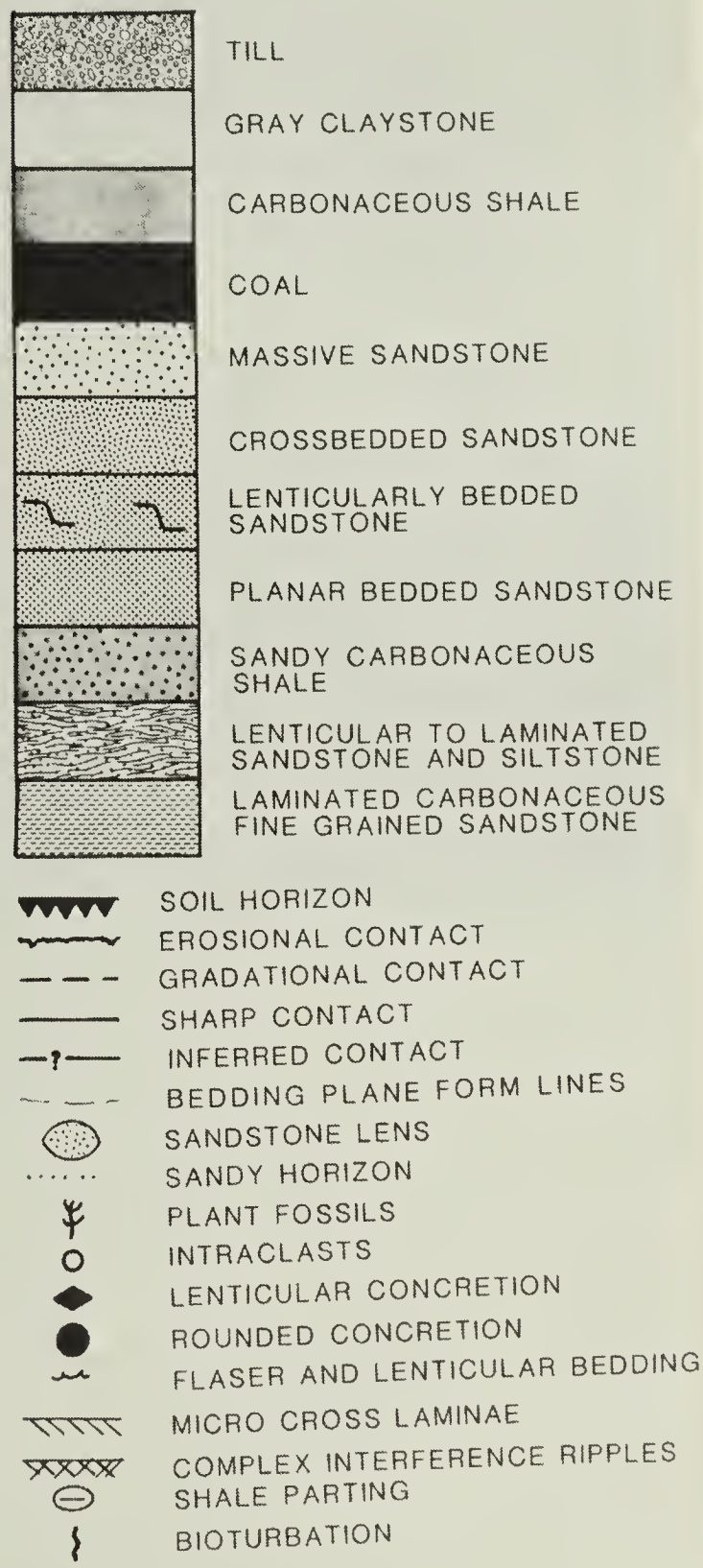
Fig. 13. macroscopic appearance of unit 4f. Note thin, even bedding.

Fig. 14. complex interference ripples of bedding surface of unit 5b.

Fig. 15. heavily bioturbated bedding surface of unit 6c.

SCHEMATIC STRATIGRAPHIC RELATIONSHIPS OF THE NORTH WALL OF THE CAGLE'S MILL SPILLWAY

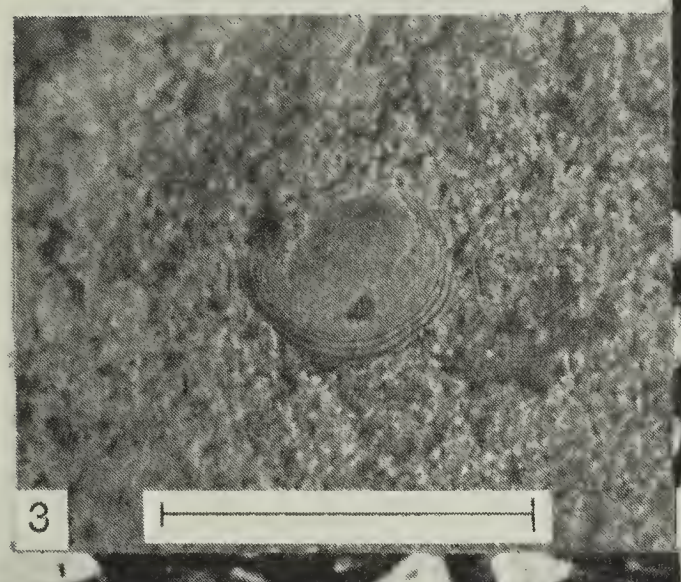
FIGURE 1



PENNSYLVANIAN EXPOSURE ON THE NORTH WALL
OF THE CAGLE'S MILL SPILLWAY

Figure 2

Plate 3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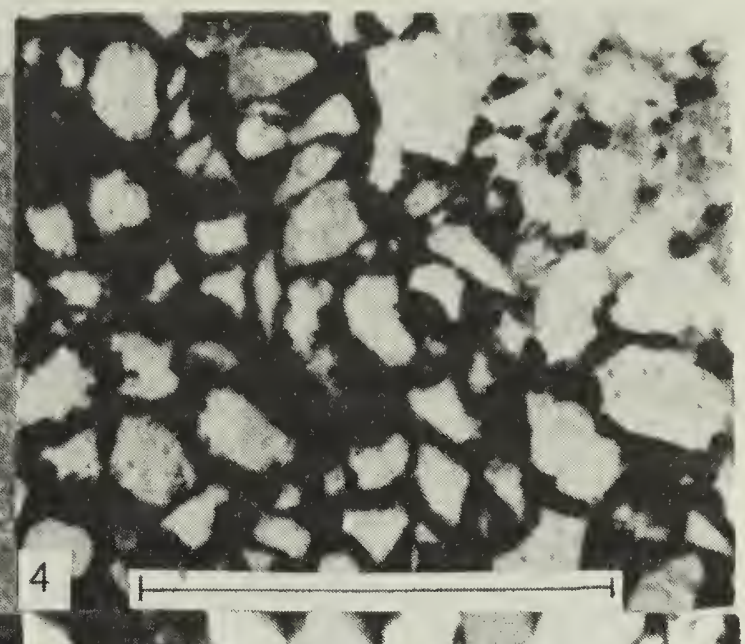
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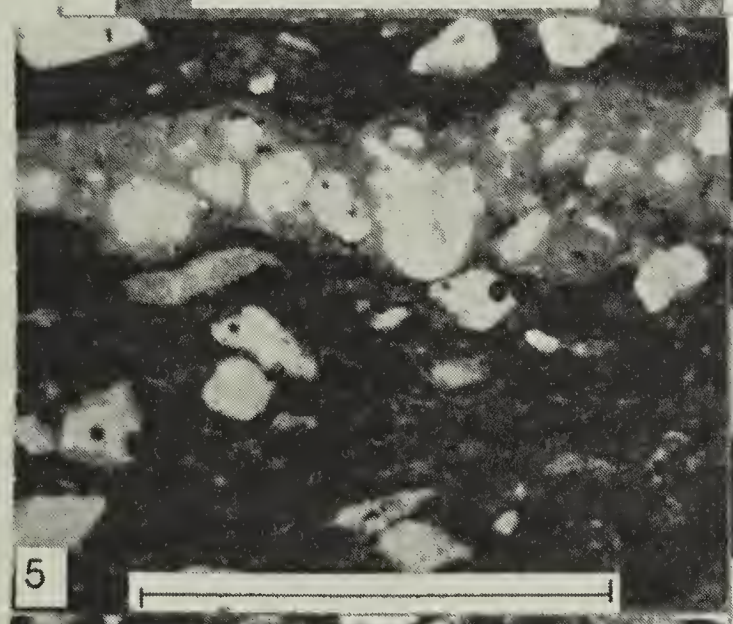
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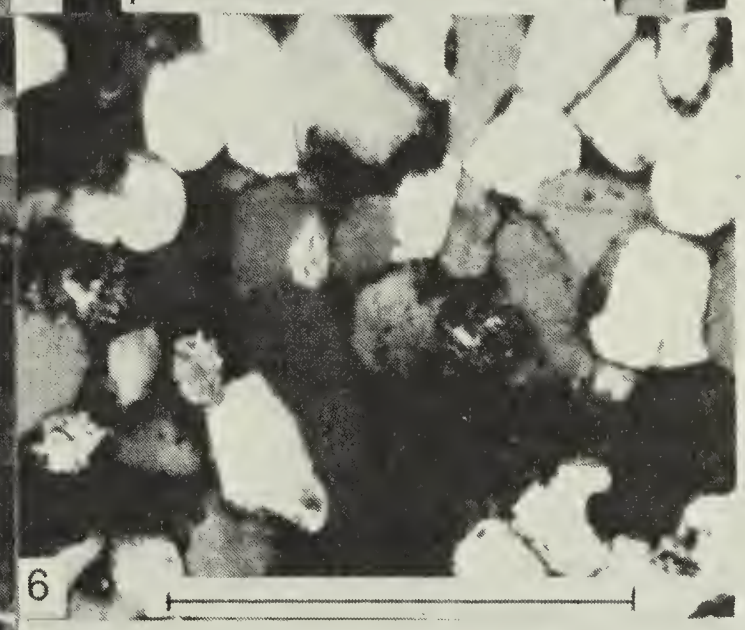
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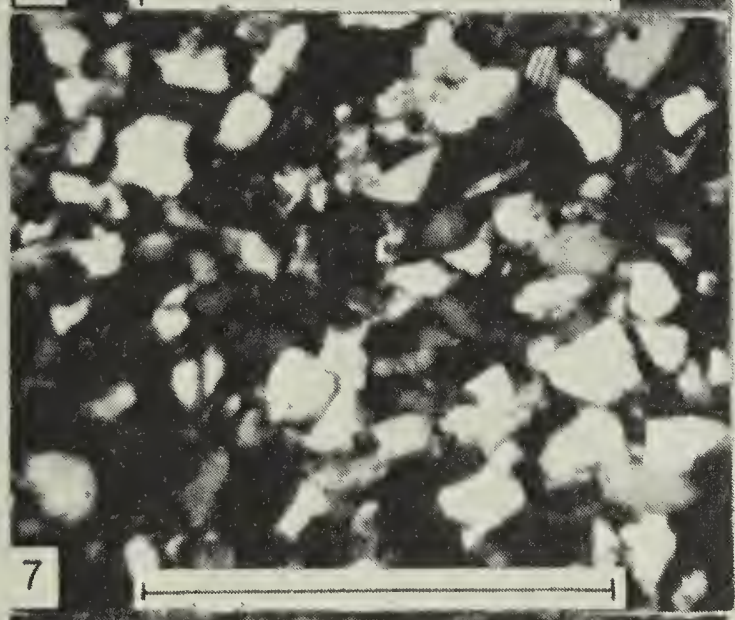
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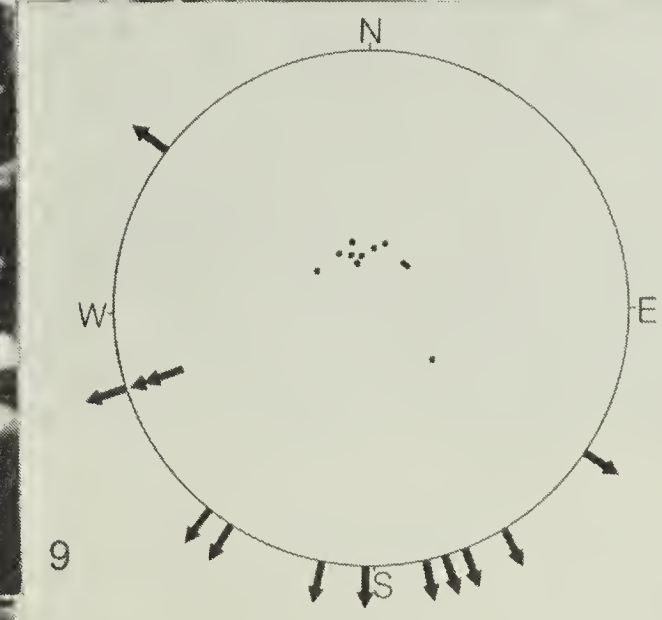


9

8

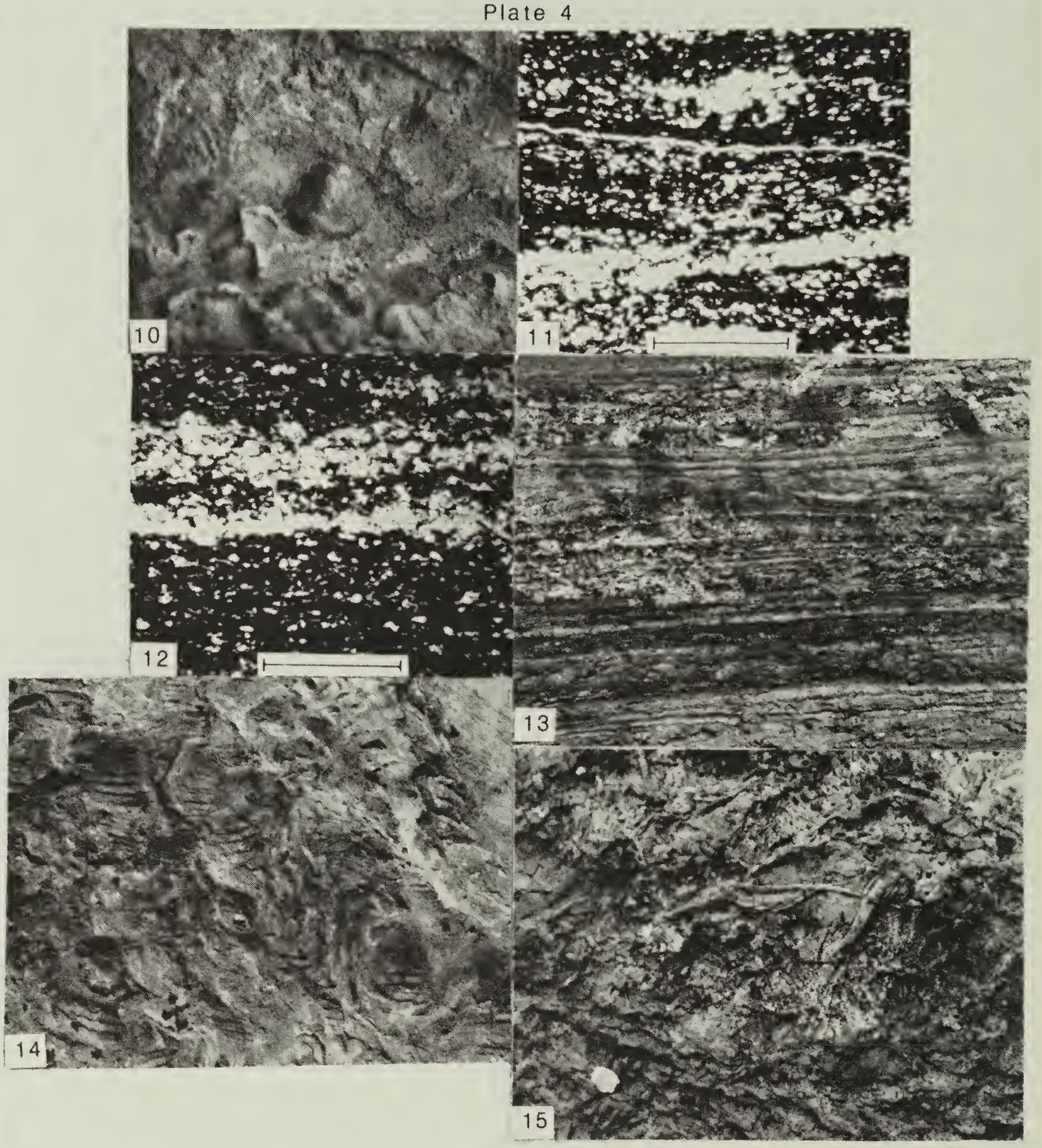
← Clay layer

Planar bedded subunit with micro cross laminae

Crossbedded subunit

← Scoured base

Plate 4



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A TURBIDITY-RELATED DELAY IN BLUEGILL (*LEPOMIS MACROCHIRUS*) REPRODUCTION AND SOME SIZE-DEPENDENT DIFFERENCES IN THE SPATIAL DISTRIBUTION OF BLUEGILL FRY

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ABSTRACT

The initiation of bluegill reproduction and the abundance and spatiotemporal distribution of bluegill fry were investigated in a central Illinois pond. High turbidity delayed successful reproduction, resulting in a short growing season. Small bluegill fry (14.0-20.0 mm total length) were generally most abundant at the 1-m depth at offshore locations, and large bluegill fry (20.5-26.5 mm) were generally most abundant at shoreline locations, supporting a littoral-limnetic-littoral migration pattern documented in published accounts. However, small bluegill fry were abundant at two shoreline locations, indicating that some bluegill fry either did not migrate to open water or returned to the shoreline at a smaller size than has been previously documented. A small mean length of age 0 bluegill in September followed the reduced growing season.

INTRODUCTION

In 1981 we initiated a study to compare the abundance and spatiotemporal distribution of the fry of bluegill and redear sunfish in a small pond in search of reasons for differences in recruitment success. Although redear sunfish failed to produce any fry, we were able to observe some effects of turbidity on bluegill reproduction as well as to describe aspects of the spatial distribution pattern of bluegill fry which differ from published accounts.

METHODS

Ringneck Pond, located in central Illinois, has a surface area of 0.6 ha, a maximum depth of 3.5 m, and a mean depth of 1.6 m. Aquatic macrophytes and filamentous algae have been absent since an application of herbicide in 1979, but some terrestrial vegetation was inundated for short intervals in 1981.

The pond was renovated in 1978 and young-of-the-year largemouth bass, bluegill, and redear sunfish were stocked in 1979. Both species of *Lepomis* suffered nearly total mortality following an excessive application of herbicide (simazine). Adult bluegill (n = 25) and redear sunfish (n = 25) were stocked in 1980; adult and juvenile bluegill (n = 95), redear sunfish (n = 43), and young-of-the-year bass (n = 50) were stocked in spring 1981.

Plexiglass fry traps (Bagenal and Braun 1978) were used to collect bluegill fry in 1981. Three habitats were sampled: shoreline (0.5-m depth, within 1 m of shore), nearshore (1.5-m depth, 4-6 m offshore), and midlake (3-m depth, approximately 30 m offshore). Traps were set at the surface at shoreline stations (I, VI, VII, X; Fig. 1), at the surface and 1-m depths at nearshore stations (II, V, VIII, IX), and at the surface, 1-, and 2-m depths at midlake stations (III, IV). Nearshore traps were moved between stations II and VIII and between stations V and IX at 2-day intervals because the number of traps was limited. Traps were fished 4 to 6 days per week, and contents were removed daily from 28 May through 11 September. The entire shoreline was inspected frequently for nesting activity throughout the sampling interval.

Every third 3-m section of shoreline was sampled with a 3- × 1.2-m seine (3.2-mm mesh) on 18 September 1981 to determine the abundance and size composition of young-of-the-year bluegill. Every third seine haul was retained for identification and measurement.

Samples from trap and seine collections were preserved in the field in 50% alcohol and returned to the laboratory for identification, enumeration and measurement. Using morphological and meristic characteristics suggested by Werner (1966), we determined that the bluegill was the only species of *Lepomis* present in trap and seine collections. In samples containing ⩽30 bluegill, all fry were measured to the nearest mm total length (TL). Thirty randomly selected fry were measured from samples containing >30 fry. Lengths were assigned to the remaining fry in proportion to the length composition of the subsample.

Daily rings in otoliths (Taubert and Coble 1977) were used to age all bluegill fry collected in traps between 26 July and 5 August (n = 48). An estimate of the interval from egg deposition to swimup (Childers 1967; Hall et al. 1970) was added to the "otolith age" to determine the date of spawning.

Daily trap catch data [transformed to $\log_{10}(\times + 1)$] were examined using Yate's weighted squares of means procedure (Steel and Torrie 1960). Treatment means were compared using the LSD test ($P<0.05$).

On each trapping day, surface turbidity was measured with a Hach Model 2100 Turbidimeter and water temperature was measured at the surface and at 1-m and 2-meter depths. A dissolved oxygen profile was determined weekly at station III using YSI Model 54 dissolved oxygen meter. Dissolved oxygen concentrations at the surface and 1-m depth were adequate for fish (⩾6 ppm; Moore 1942) throughout the sampling interval but were generally too low (<2ppm) at the 2-m depth until early August.

RESULTS

As a result of high spring runoff from an adjacent plowed field, turbidity was high in Ringneck Pond when trapping began in late May (Fig. 2). Turbidity declined in early June, remained relatively constant through mid-June, and then declined rapidly to <10 NTU by mid-July. Slow settling of introduced soil particles, rather than new runoff or wind-induced wave action, was responsible for the extended interval of high turbidity.

The high turbidity in May and June has a marked effect on the water temperature profile. Surface water absorbed most of the solar radiation and warmed rapidly, resulting in a stable temperature gradient which insulated subsurface water. Midday water temperatures at the surface and at 1 meter down differed by as much as 12 C (4 June) and rarely by less than 6 C until turbidity declined in early July. Thereafter, water temperature at the 1-m depth increased rapidly and differed from the surface temperature by no more than 2.5 C from 19 July through the end of the summer.

Nesting activity was first observed on 8 July, when five bluegill nests were discovered along the dam (Fig. 1), and continued sporadically through mid-August. Bluegill nesting activity was concentrated along the dam throughout the summer and peaked in late July when 24 males were observed guarding nests.

Bluegill fry (n = 4,554) were collected in traps from 25 July through the end of the sampling interval (11 September). Consistent with our observations of nesting activity, otolith-derived ages of bluegill fry collected between 26 July and 5 August indicated that successful spawning began during the first week of July. Thus, the first successful spawn occurred at least a month later than the typical date of first spawning for bluegill in central Illinois (Childers 1967) and 1.5 months later than the initiation of spawning in Ringneck Pond in 1980 (unpublished data).

Analysis of the spatial distribution of bluegill fry was limited to fish 14-26.5 mm in length because smaller fry were not sampled in proportion to their abundance and too few larger fry were collected. Two length categories were considered: 14-20 mm and 20.5-26.5 mm.

Fry were not uniformly distributed throughout the pond ($P<0.05$; Table 1), and small and large fry were distributed differently ($P<0.05$). Both size groups were significantly more abundant at the north end of the pond at trap locations VII_0 $VIII_1$ (subscripts indicate the depth of the trap in meters) than at all other trap locations. The lowest densities of both size groups occurred at nearshore and mid-lake surface locations (II_0, III_0, IV_0, V_0, $VIII_0$, IX_0). Densities at the 1-m depth were always greater than at the surface at the same location. However, for large fry, the difference was significant only at station VIII.

Small and large fry differed most in their use of shoreline habitat. Shoreline traps accounted for 61% and 41% of the catch of large fry and small fry respectively, indicating that large fry were more closely associated with the shoreline than were small fry. Also, small fry were significantly more abundant at the 1-m depth than at the 2-m depth, while large fry were equally abundant at both depths.

Catch rates of bluegill fry in the September seining collection were highest at the north end of the pond, which was consistent with the distribution of fry collected in traps. The length distribution of bluegill collected by seining ($\bar{X} = 21$ mm) was similar to that of bluegill collected in traps in the last week of sampling ($\bar{X} = 19$ mm). However, some fry collected in seine samples were larger (>40 mm) than any collected in traps.

DISCUSSION

Bluegill generally begin spawning when water temperature reaches 20-27 C (Childers 1967). In contrast, successful bluegill reproduction did not begin in Ringneck Pond until turbidity declined in early July, even though surface temperatures had reached 27 C by 3 June (Fig. 2). High turbidity could interfere with bluegill reproduction directly, by a mechanism such as impairment of visual spawning cues, or indirectly, by reducing the rate of warming of subsurface water. A direct effect was indicated in Ringneck Pond, because successful reproduction began during an interval when turbidity was declining rapidly and water temperature at the 1-m depth was relatively constant. Because turbidity levels equal to or greater than those recorded in Ringneck Pond are common in nature (Buck 1956, Gardner 1981), high turbidity may often disrupt the normal temporal distribution of spawning activity. Buck (1956) associated high turbidity with reduced production of bluegill fry in Oklahoma ponds but did not document a direct relatinship between the initiation of reproduction and turbidity.

Werner (1967) concluded that bluegill fry in Crane Lake, Indiana, migrated to the limnetic zone soon after leaving the nest and returned to the littoral zone when they attained a size of 20-25 mm. Others have found small bluegill fry in the limnetic zone, but the size at which these fry returned to the littoral zone varied: 12 mm (Storck et al. 1978), 15 mm (Keast 1980), and 15-20 mm (Beard 1982). The high density of small bluegill fry at Ringneck Pond shoreline stations VI_0 and VII_0 indicates that a fraction of the population of fry either did not participate in the offshore migration or returned to the shoreline at a very small size. The substantial use of shoreline habitat by small bluegill fry may have reflected the poor definition of limnetic and littoral habitats resulting from the small size of the pond and the absence of aquatic vegetation. Regardless, substantial movement of bluegill fry was indicated, since they became dispersed throughout most of the pond even though spawning was concentrated along the dam at the south end.

The predominately shoreline distribution of large bluegill fry in Ringneck Pond was consistent with the observations of Werner (1967) and Beard (1982). However, since vegetative cover was absent in Ringneck Pond, littoral vegetation is not a requisite for shoreline residence by large bluegill fry.

Our results are in agreement with Werner's (1966) finding that bluegill fry occupying open water are relatively rare near the surface. However, bluegill fry <12 mm (essentially absent from Werner's and our collections) may exhibit a different vertical distribution. Storck et al. (1978), using towed nets, found higher densities of 5-11 mm bluegill fry at the surface than at the 2-m depth in the limnetic zone of a large Illinois reservoir.

The mean length of age 0 bluegill in Ringneck Pond in September (21 mm) was much less than the 40-70 mm range reported by Carlander (1977) for other midwestern waters. Small length at the end of the growing season has been associated with low overwinter survival of age 0 largemouth bass (Aggus and Elliott 1975; Shelton et al. 1979) and smallmouth bass, *Micropterus dolomieui* (Oliver and Holeton 1979). Furthermore, Beard (1982) found that for bluegill, the date of first fry dispersal from the nest was one of the two most important variables affecting yearclass strength. Thus, by reducing the mean size attained by young-of-the-year, the turbidity-caused spawning delay in Ringneck Pond may have had a detrimental impact on the future strength of the 1981 bluegill yearclass.

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Table 1. Geometric means of numbers of small and large bluegill fry collected daily in Ringneck Pond. Means within a size group without a letter in common are significantly different ($P<0.05$). Subscript indicates depth of trap in meters.

Small Fry		Large Fry	
Station	Mean density	Station	Mean density
VII_0	9.35a	VII_0	1.42a
$VIII_1$	8.00a	$VIII_1$	1.15a
IV_1	4.09b	VI_0	0.60b
III_1	2.66c	X_0	0.47bc
V_1	2.53cd	I_0	0.43bcd
VI_0	2.35cd	IX_1	0.42bcde
II_1	2.28cd	II_1	0.28bcdef
IX_1	1.95cde	III_1	0.22bcdef
IV_2	1.77de	IV_2	0.19cdef
I_0	1.48ef	IV_1	0.17cdef
X_0	1.29f	V_1	0.13cdef
III_2	1.23f	III_2	0.11def
II_0	1.19f	V_0	0.08ef
$VIII_0$	1.05fgh	$VIII_0$	0.08ef
IV_0	0.99fgh	IV_0	0.06ef
III_0	0.82gh	II_0	0.04ef
IX_0	0.72h	IX_0	0.04ef
V_0	0.59h	III_0	0.02f

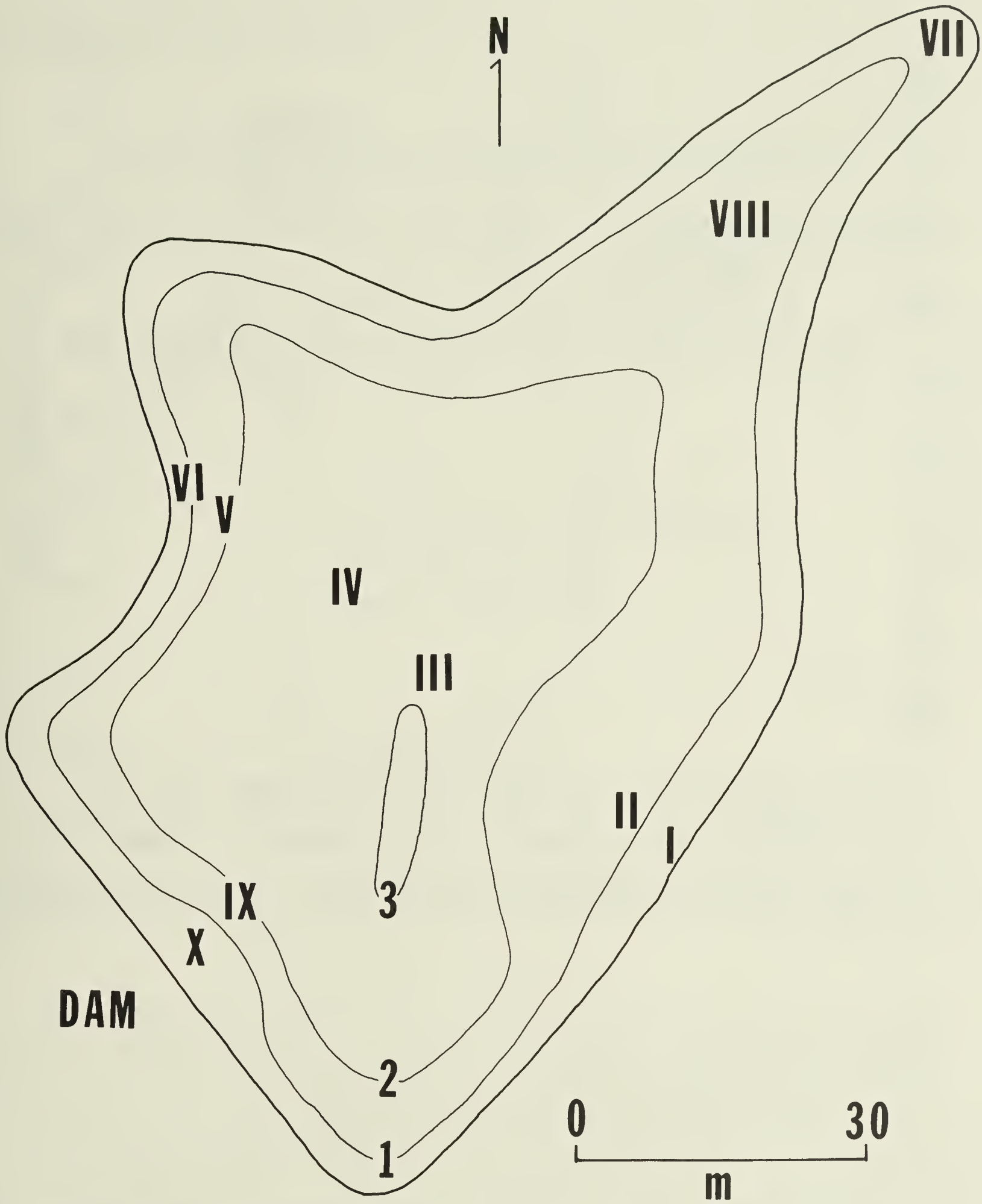

Fig. 1. Ringneck Pond, showing trap locations.

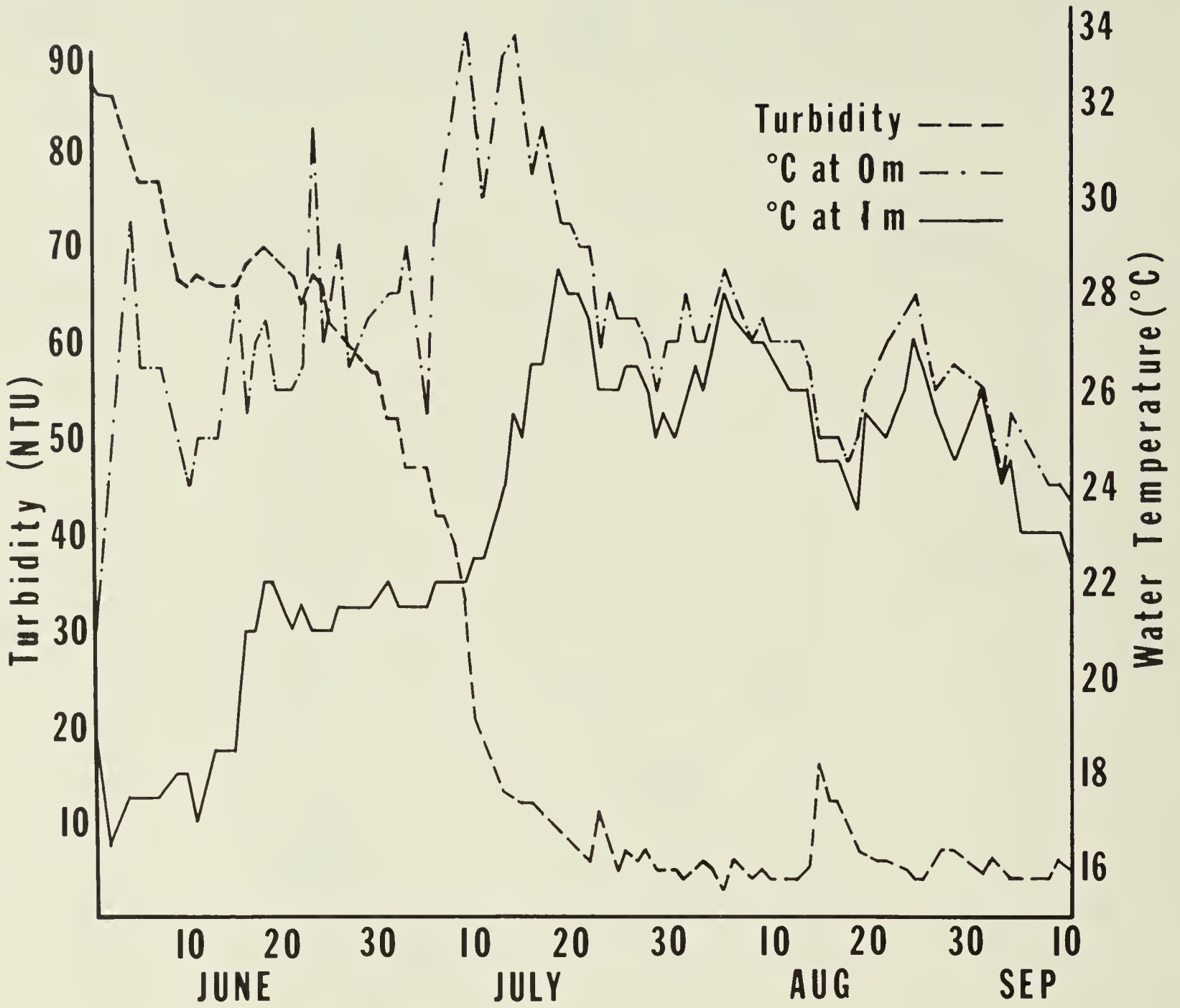

Fig. 2. Surface turbidity and water temperature at the surface and at 1-m depths in Ringneck Pond in 1981.

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ASHING INSOLUBLE OXIDATION RESIDUES TO DETERMINE PERCENTAGES OF COAL OXIDIZED BY AQUEOUS SODIUM DICHROMATE

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ABSTRACT

Illinois #6 bituminous coal, North Dakota lignite, Illinois #2 bituminous coal, a solvent-refined lignite (North Dakota) and a solvent-refined coal were oxidized with aqueous sodium dichromate. The insoluble residues were ashed and a correlation coefficient of 0.974 was obtained between the weight of ash obtained and the percent of carbon oxidized.

Sodium dichromate has been used extensively to oxidize different coals and lignite, e.g., Hayatsu *et al.* (Hayatsu, 1975, 1978, 1981) have oxidized Illinois #2 bituminous coal, North Dakota lignite and anthracite coal. Lignite coal and its solvent-refined product have been oxidized by sodium dichromate. (Duty, 1980), and from these studies a question has been raised about the percentage of coal oxidized by the authors (Duty, 1981). Consequently, we began this study to ascertain if ashing the insoluble residues from these oxidation experiments could be used with reasonable success.

In this study the following were oxidized; Illinois #6 bituminous coal, North Dakota lignite, and Illinois #2 bituminous coal. In addition, a solvent refined lignite (North Dakota) and a solvent refined coal were oxidized. All coals were dried in a vacuum desiccator over phosphorus pentoxide. The analytical data for these coals is found in Table 1.

One way to determine the extent of oxidation would be to determine the percent carbon in the insoluble oxidized residue and compare this with the percent carbon in the original coal. To avoid the analysis for the percent carbon in the insol-

uble residue, this study was undertaken to investigate the ashing of the insoluble residue from the dichromate oxidations to ascertain if these results could be used to predict the amount of coal oxidized. If a sufficiently high coefficient of correlation exists between the percent carbon oxidized in these reactions and the weight remaining in the ashing procedure, a yield percent should be predictable from the ashing weight. Therefore, this study set out to prove that this coefficient of correlation is sufficiently large to predict with reasonable accuracy the percentage of coal oxidized from the weight of the ash of the insoluble residue. Two coefficients of correlation were determined between the percent carbon lost (% C in raw coal minus % C in insoluble residue) and 1) the weight loss in ashing the insoluble residues and 2) the weight of the ashed insoluble residues.

The mineral content of the oxidized insoluble residue should remain reasonably constant throughout the ashing procedure, consequently, the loss in weight by ashing should correlate well to the carbon content oxidized, e.g., the amount of coal oxidized. Carbon dioxide is a known by-product from dichromate oxidations (Guyout, 1920), consequently, the inorganic carbonates could be generated by these oxidations and cause a weight increase in the ashed residues which would erroneously lower the oxidation yields. To ascertain if this were a source of error, the carbonate content of the oxidized insoluble residues was determined by measuring the carbon dioxide released when the residues were decomposed by hydrochloric acid. The percentage weights of the carbonates in the oxidized residues as measured by this technique were always less than 0.16% (Duty, 1981).

Since the residues also may contain unreacted sodium dichromate and chromium oxide, each of these was dried under the same conditions as the residues and ashed. These duplicate ashing experiments are shown in Table 1 which clearly show these compounds, as expected, would contribute very little to the weight loss of the ashed oxidation residues.

For the first coefficient of correlation measurement the percent of coal oxidized, taken as the difference in carbon content between the original (mf) coal and the insoluble residue, was compared to the weight lost in ashing. These values are shown in Table 2 for eight different reactions, and the coefficient of correlation between these two parameters was calculated and found to be a very low correlation, 0.774. This low coefficient of correlation is understandable because in the ashing procedure the hydrogen, nitrogen and sulfur are lost as well as carbon, and these values may well contribute to a low coefficient of correlation.

In these oxidation experiments with sodium dichromate, an insoluble chromium oxide is produced, and consequently, if the coal is oxidized, the generation of chromium oxide should parallel the extent of coal oxidized. The water soluble sodium dichromate should not interfer because the water soluble compounds are removed, along with the carboxylic acids produced, when the residues are extensively washed with water. Therefore, a second correlation of coefficient was calculated for the percentage of coal oxidized (the weight of the carbon lost between the original coal and the insoluble residue) compared to the weight of the ash obtained from the insoluble residues. This coefficient of correlation for this comparison came out to be 0.974. The standard error of estimate was calculated to be 2.9%, and the probable error was 1.96%, i.e. if one uses the weight of ash in the insoluble residues, he has a 50% chance of predicting the percentage of coal oxidized within a 2% error.

In these oxidation experiments, the reactions were run with an excess of dichromate and a limited amount of dichromate. This was done to duplicate the experimental

runs with dichromate in previous experiments (Duty, 1980, 1981). Excess dichromate was indicated by an orange filtrate, and limited dichromate was determined by a green filtrate at the completion of each experiment. To ascertain whether limited or excess dichromate would make a difference in predicting the oxidation yields from their ashed residues, a coefficient of correlation was determined for each. The excess had a 0.985 coefficient of correlation and the limited dichromate coefficient was 0.939. Evidently, the generation of chromic oxide enhances the predictably of ascertaining the precentage of coal oxidized.

The coefficient of correlation calculations were determined by using the equation: coefficient of correlation $= \frac{\Sigma x_i y_i}{\sqrt{\Sigma x_i^2 \Sigma y_i^2}}$

This coefficient of correlation (Laitinen, 1975) has its y intercept fixed at zero which corresponds with our date; e.g. when there is no coal oxidized the chromium oxide is zero.

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Table 1. Elemental Analysis for Coals

	%C	%H	%N	%S	%O[a]	%Ash
Ill. No. 2 Coal	69.4	5.81	1.27	2.11	11.4	3.34
Ill. No. 6 Coal	69.2	4.72	—	4.42	8.46[b]	12.4
North Dakota Lignite	65.71	3.77	0.78	0.89	19.90	8.95
Solvent Refined Lignite	89.3	5.8	1.1	0.9	2.9	~0.0
Solvent Refined Coal	87.2	5.5	1.8	1.2	4.3	~0.0

[a]oxygen was determined by difference
[b]oxygen was determined by difference assuming a nitrogen content of 1.00%. The dmmf coal had a nitrogen content of 1.29%.

Table 2. Ash Content Versus Quantity of Coal Oxidized

Oxidation Reaction	g. of carbon in coal sample (mf)	g. of carbon in insoluble residue	% Loss of Original C.	g. of carbon oxidized	g. of insoluble residue	% Ash of insoluble residue[a]	g. of Ash of insoluble residue
IL#6 (limited)	6.9	5.9	14.5%	1.0	26.97	70.23 ± 1.15	18.94
IL#6 (excess)	6.9	6.2	10.1%	0.7	15.04	41.52 ± 0.15	6.14
NDL (limited)	6.6	4.9	25.8%	1.7	30.76	61.03 ± 1.02	18.77
IL#2 (limited)	7.4	7.3 ± 0.07[a]	13.5%	0.1	14.17	31.45 ± 0.18	4.46
SRC (excess)	7.4	6.5	12.2%	0.9	26.19	61.64 ± 0.14	16.14
SRL (limited)	8.8	4.2 ± 0.08[a]	52.3%	4.6	39.45	75.08 ± 0.01	29.62
SRL (excess)	8.9	4.2 ± 0.08[a]	52.8%	4.7	43.56	80.19 ± 0.01	34.93
SRL (excess)	8.9	6.0 ± 0.09[a]	32.6%	2.9	34.71	69.62 ± 0.90	24.16
Cr_2O_3 (expt. std.)						98.73 ± 0.90	
$Na_2Cr_3O_7$ (expt. std.)						97.03 ± 0.90	

[a]duplicate determinations

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FORAGING ABILITY, DOMINANCE RELATIONS AND COMPETITION FOR FOOD BY FOX AND GRAY SQUIRRELS

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ABSTRACT

In central Illinois fox squirrels are most common in woodlots, whereas gray squirrels are most common in cities. Several studies have suggested that food is a limited resource during the winter breeding season, therefore we tested the foraging abilities and dominance relations of captive squirrels to assess possible mechanisms of competition between these sympatric species. Female gray squirrels were more efficient at finding buried nuts than female fox squirrels, but female fox squirrels kept female gray squirrels from access to food during breeding seasons. Neither species was dominant during the non-breeding season. These results are consistent with the hypothesis that aggressive behavior of female fox squirrels influences the distribution of gray squirrels in woodlots during the main breeding season (winter) and that this aggression reflects competition for food.

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INTRODUCTION

Woodlots in Champaign County, Illinois contain mostly fox squirrels (*Sciurus niger*), whereas larger cities contain nearly all gray squirrels (*S. carolinensis*) (Nixon et al., 1978). Several studies have indicated that availability of food, particularly mast, often limits the abundance of fox and gray squirrels in woodlots during winter (Barber, 1954; Christisen and Korschgan, 1955; Nixon and McClain, 1969; Nixon et al., 1975), and gray squirrels appear to shift their use of habitat during winter

(Brown, 1984). Thus competition for food may occur (Flyger and Smith, 1980). As part of a study of competition between natural populations of these species (Brown, 1984), we conducted two types of laboratory experiments to explore the role of foraging abilities (exploitation) and dominance relations (aggression) in competition for food.

If food is in fact limiting, then differing foraging abilities of fox and gray squirrels should lead to different abilities to exploit sparse food supplies and would provide a mechanism for competitive exclusion. Smith and Follmer (1972) concluded that fox and gray squirrels had very similar preferences with respect to the five species of naturally occurring foods tested. Fox squirrels consumed nuts faster than did gray squirrels, but their study involved only a few individuals. Some work has been done on recovery of buried nuts by gray (Thompson and Thompson, 1980) and fox squirrels (Cahalane, 1942), but few quantitative or comparative data on the foraging abilities of fox and gray squirrels are available. Therefore our first set of experiments concerned the ability of these two species to find and consume buried nuts. If gray squirrels change their use of woodlots in central Illinois because of exploitative competition for food, we would expect fox squirrels to be more efficient foragers.

Analysis of aggressive interactions in the laboratory can be used to study the mechanisms underlying competitive interactions in nature, as done by Conley (1976) and Koplin and Hoffman (1968) with microtine rodents, Blaustein and Risser (1976) with kangaroo rats; and Sheppard (1971) and Heller (1971) with chipmunks. Ackerman and Weigl (1970) investigated agonistic behavior in captive red (*Tamiasciurus hudsonicus*) and gray squirrels by recording the exclusive or shared use of nest boxes. They concluded that the antagonism between the two species was low, as demonstrated by the frequent sharing of nest boxes. Because we were interested in competition for food, we simulated a food shortage in the laboratory and studied the aggressive behavior of hungry fox and gray squirrels. If gray squirrels change their distribution in woodlots because of interference by fox squirrels, we would expect fox squirrels to win aggressive encounters.

MATERIALS AND METHODS

In April to June of 1981 and 1982 and October of 1983 fox squirrels were live-trapped from oak-hickory and oak maple woods in Champaign and Vermillion Counties, Illinois; gray squirrels were trapped from yards of residences in the cities of Champaign and Urbana. Because we wanted to minimize the confounding effects of sex and age and because aggressive behavior of adult females has been implicated in population regulation of squirrels (Nixon et al., 1975; Havera and Nixon, 1978), only adult females were used. Squirrels were maintained in large outdoor cages (1 × 2 × 2-m) and supplied with nest boxes. English walnuts, a preferred food, supplemented the standard diet of Purina rat chow and water for the first week. All animals were maintained for at least six weeks prior to experimentation in order to acclimate them to laboratory conditions.

Foraging studies were conducted during the morning hours from 13 June 1981 to 22 July 1981 and from 14 July 1982 to 10 September 1982. Eight adult female gray squirrels and seven adult female fox squirrels were tested for their foraging abilities in a 3 × 3 × 2.5-m experimental enclosure that was constructed of 2-cm wire mesh and had a dirt floor. The soil was maintained in a friable and moist con-

dition during foraging trials. Commercial walnuts were used in these trials rather than native mast (black walnuts or acorns) to insure a low incidence of wormy or moldy nuts, which could have affected results because squirrels often avoid unsound nuts (Dennis, 1930; Lloyd, 1968). English walnuts may be more difficult for squirrels to find than native mast because commercial walnuts are cleaned and washed. However, flotation methods that are often recommended to sort out sound from unsound nuts proved to be unreliable with acorns and walnuts (26% of 250 nuts tested were classified incorrectly).

Six small, unshelled English walnuts were placed in the enclosure just prior to the introduction of a squirrel that had been starved for 48 hours. One nut was placed on the surface of the soil (surface nut), one just under the surface (subsurface nut) and the remainder with one, two, three and four cm of soil above the top of each nut, respectively. The positions of the nuts on a 0.3-m grid were determined using a random number table. The surface of the soil was raked after the nuts were buried to eliminate any visual cues of their location. Weather conditions, squirrel activity and movements within the enclosure, the amount of time spent foraging, the time required to open the nuts (gnawing time) and the time required to consume the meats (eating time) were recorded for each trial.

An experiment was terminated when the squirrel found all six nuts, remained at one spot for more than 20 minutes, or went more than 30 minutes without finding an additional nut. The last two criteria were established after repeated observations which showed that additional time in the enclosure did not produce different results. After each experiment undetected and uneaten nuts were checked for soundness. Each squirrel was given five opportunities to forage at one-week intervals. Data for the number of nuts found was based on the best three trials for each squirrel because some learning was involved in the initial trials and because the foraging of squirrels was sometimes disturbed by other animals or bad weather.

Dominance relationships were established by using all possible pairwise combinations of interspecific encounters between three fox and three gray squirrels during the non-breeding season (September 1981) and the winter breeding season (January 1984) and between four of each species during the summer breeding season (July and early August 1982). Different animals were used each year. Squirrels were starved for 48 hours prior to being placed into the enclosure (described above) and rested one week between encounters. Vaginal smears were taken during the trials conducted in 1982 and 1984 to determine if any of the animals were in estrus, since these studies were conducted during breeding seasons.

A small metal feeder that allowed squirrels to feed on English walnut meats was attached to the enclosure wall at ground level. Behavior of the paired fox and gray squirrels was observed with binoculars from a blind 15 m from the enclosure. Dominance was determined by the ability of one squirrel to maintain possession of the feeder in spite of efforts of the other squirrel to feed. Possession was established by displacing and/or chasing off the other squirrel. Most encounters were short in duration and aggressive behaviors occurred almost exclusively at the feeder. In all but one of the 34 trials conducted, a dominant animal was determined by its aggressive behavior at the feeder; the other trial was scored as a draw. Experiments were terminated when the dominant squirrel relinquished the feeder.

RESULTS

Both species of squirrels examined, opened and ate walnuts in a very similar manner during the foraging trials. Occasionally, the nut was eaten where it was found, but more often the squirrel opened and consumed the nut elsewhere. After each successive nut was found it was taken to the same spot and eaten. Squirrels that consumed all six nuts in the enclosure were still hungry; they continued to forage and consumed an additional introduced nut. Successful squirrels usually found and consumed the nut on the surface first (19 of 24 trials). The incidence of wormy and moldy nuts was low (<1%) and created no complications. The time taken to find or to consume nuts did not change significantly during a trial for gray squirrels that found all 6 nuts. (one-way ANOVA; $F = 0.87$; 5, 48 d.f.; $P > 0.1$ and $F = 2.05$; 5, 60 d.f.; $P > 0.05$, respectively). However, there was a significant positive correlation between the order in which nuts were found by gray squirrels and the depth at which they were buried, deeper nuts being found later in the trial ($r = 0.57$, d.f. = 64, $P < 0.001$). Fox squirrels did not find enough nuts to allow a similar analysis.

Although the larger fox squirrels consumed English walnuts significantly faster than gray squirrels, gray squirrels found significantly more nuts (Table 1). None of the seven fox squirrels found all six nuts, although some individuals spent up to 25 minutes foraging without success. Conversely, five of the eight gray squirrels found all six nuts during one or more of their foraging trials.

The results from the non-breeding season showed no trend in dominance relations, but those from the breeding seasons showed significantly more wins by fox squirrels than expected if wins were distributed evenly (Table 2). Low sample sizes from the non-breeding season may lead to a Type II error, which might indicate a difference between breeding and non-breeding season behavior even if none existed. A Fisher exact test was applied to the dominance data from all three periods to determine if a difference did occur. A highly significant difference resulted ($P = 0.007$, $N = 33$). The adult female fox squirrels weighed more than the grays, which is normal for these two species (Brown and Yeager, 1945). Vaginal smears taken during the 1982 and 1984 trials indicated that none of the squirrels had been or was in estrus, even though these trials were done during normal breeding seasons.

DISCUSSION

Fox and gray squirrels foraged in similar ways in our experiments, and in nature there is almost complete overlap in food preferences and food habits of these species (Nixon et al., 1968, Smith and Follmer, 1972). Winter food consists largely of mast. Fox and gray squirrels may respond differently to English walnuts than they would to native mast owing to differences in scent. Thus native foods may be easier to find than English walnuts, and use of native mast in foraging trials might reduce the differences we saw between foraging abilities of fox and gray squirrels. Fox and gray squirrels find buried nuts using olfactory stimuli (Cahalane, 1942; Thompson and Thompson, 1980) and consequently nuts buried more deeply may be more difficult to find. The positive correlation between the order in which nuts were found and the depth at which they were buried supports this idea. Although neither squirrel species normally buries nuts deeper than 1 to 2 cm (Cahalane, 1942; Thompson and Thompson, 1980), these animals are often forced to forage for food covered by snow. The superior ability of gray squirrels to find buried nuts should be of great competitive advantage during these times, and during periods of food shortage they should be able to displace fox squirrels if only exploitative competition were important.

Little is known about the behavioral relationships between fox and gray squirrels in natural populations but our results indicate that fox squirrels should win aggressive encounters during breeding seasons. Bakken (1952) observed aggressive interactions in fox and gray squirrels and noted that fox squirrels were more aggressive as food supplies declined over the winter. Berry et al. (1978) reported that dominance hierarchies of gray squirrels within an enclosure may change with the addition of more animals and a different size enclosure. Although our procedures differed, the size of our test enclosure may have affected squirrel behavior.

The difference in our results for breeding and non-breeding seasons (Table 2) reflects seasonal changes in aggressive behavior. Although none of our animals were in estrus during the encounters, aggressive behavior in females generally increases during the breeding season (Bakken, 1952; Taylor, 1966; Nixon et al., 1975). The 1981 encounters were carried out during the early fall, after the summer breeding season, when adult females might be less aggressive. The overall dominance of fox squirrels is consistent with Grant's (1972) finding that the larger of two otherwise similar rodent species is usually the dominant one.

While the results of our laboratory experiments may not reflect precisely the relationship between squirrels in nature, they are consistent with the hypothesis that aggressive behavior of fox squirrels causes the change in habitat use by gray squirrels during winter. Female fox squirrels may need to displace gray squirrels in woodlots during the winter breeding season because gray squirrels are more efficent foragers. Thus gray squirrels may reduce the availability of stored mast below levels that will support breeding fox squirrels.

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Table 1. Comparative foraging abilities of fox and gray squirrels. Values are $\bar{X} \pm 1$ SE.

	n	Gnawing time (sec)	Eating time (sec)[a]	No. nuts found[b]
Fox	7	35.8 ± 13.3	160.0 ± 12.2	1.6 ± 0.5
Gray	8	76.8 ± 23.7	262.0 ± 43.0	4.1 ± 0.8

[a]Student's t-test, $P < 0.05$ for comparison between species.
[b]Student's t-test, $P < 0.025$ for comparison between species.

Table 2. Results of round-robin aggressive encounters between adult female fox and gray squirrels.

	Mean Body Mass (N)		Observed Number of Wins (Expected)		
	fox	gray	fox	gray	draws
Winter breeding Season, 1984[a]	877 (3)	490 (3)	9 (4.5)	0 (4.5)	0
Summer breeding Season, 1982[b]	725 (4)	475 (4)	13 (7.5)	2 (7.5)	1
Non-breeding Season, 1981[c]	813 (3)	603 (3)	4 (4.5)	5 (4.5)	0

[a]$P = 0.004$, binomial exact test
[b]$P = 0.006$, binomial exact test
[c]$P = 0.49$, binomial exact test

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MACROINVERTEBRATE POPULATIONS IN A THERMALLY IMPACTED RESERVOIR

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ABSTRACT

The macroinvertebrate community of Duck Creek Reservoir, a thermally impacted impoundment, was examined over a twelve month period to determine the effect of heated effluents on distribution and abundance. The Shannon-Weaver function, $\overline{H}$, was used to express species diversity. The 34,139 organisms encountered were represented by 57 taxa including Nematomorpha, Annelida, Gastropoda, Ephemeroptera, Odonata, Hemiptera, Trichoptera, Coleoptera, and Diptera. Eighty-four percent of all individuals were tendipedid larvae with one species, *Glyptotendipes lobiferus*, contributing 57 percent of the total. Other dominant species present were *G. senilis*, *Dicrotendipes nervosus*, *Cyrnellus marginalis*, *Pentaneura monilis*, and *Caenis sp*. The number of individuals per square meter increased when water temperature was moderately elevated, but abundance and diversity both were significantly reduced by higher temperature at the immediate discharge area. Seasonal variation in the abundance of organisms appeared consistent with emergence patterns of the dominant species. Bathymetric distribution showed diversity and abundance greatest between two and four meters with a rapid decline between 6 and 10 meters. Below 10 meters, organisms were rarely encountered.

INTRODUCTION

In recent years, there has been considerable research into the effects of waste heat on aquatic habitats (Dahlberg and Conyers, 1974; Logan and Mauer, 1975;

Benda and Profitt, 1974). These studies and others have shown that macroinvertebrate diversity and abundance can be influenced by thermal effluents (Coutant, 1962; Parkin and Stahl, 1981; Warriner and Brehmer, 1966; Webb, 1981; and White, 1974). In this study, multi-plate samplers were used exclusively for collecting macroinvertebrates because depths were often greater than sixteen meters and anoxic conditions in the reservoir would have produced considerable sampling bias.

The primary objectives of this study were to characterize the macroinvertebrate community of Duck Creek Reservoir, and to determine the effect of heated effluent on macroinvertebrate community structure. This was accomplished by positioning Hester-Dendy samplers at various depths and thermal exposures, determining community structure with the use of a diversity index, establishing seasonal patterns of distribution and correlating macroinvertebrate distribution with temperature data.

DESCRIPTION OF THE STUDY AREA

Duck Creek Reservoir is located in Fulton County, approximately 3.2 km southwest of Canton, Illinois (Fig. 1). It was constructed to supply cooling water for a coal fired generating station by damming Duck Creek. In general, the reservoir has a north-south orientation and consists of one main channel with several small side arms. The sediment composition of the substrate is primarily a sand-clay mixture.

Work on the reservoir began in late 1975 and was completed in early 1976. The basin was filled by pumping water from the Illinois River. After the initial filling, additional river water has not been used. Located at an elevation of 161.5 meters above sea level, the surface area of the reservoir covers 256.4 hectares and has a total volume of 4.8×10^7 cubic meters. The maximum depth in the main channel is approximately 18.3 meters.

In addition to a rock dam which impounds Duck Creek, there is an inverted weir dam at the southern end of the reservoir where the generating station is located. Water that is to be used for cooling purposes is drawn into the plant below the inverted weir dam at a depth of 6.4 meters. Two pumps, each with a design capacity of 435 cubic meters per minute, move the water into the plant. During summer months, both pumps operate to circulate 795 cubic meters per minute.

The plant is a coal-fired facility containing a single 416.5 megawatt unit which has a design capacity of 3,970 BTU per kilowatt and produces 380 megawatts. The design condensor temperature rise (ΔT) is 7.4°C. After a single circulation, water leaves the plant through a 305 meter long discharge canal. Before re-entering the reservoir, heated water is passed over an energy dissipating spillway with a height of 12.2 meters.

Duck Creek Reservoir has a drainage basin of 4,015 hectares and also receives treated waste water from the City of Canton. The upper and lower parts of the reservoir are separated by a haulage road, but a conduit between the two serves to maintain an adequate water level in the lower reservoir. Water in the reservoir above the haulage road is unaffected by the elevated water temperature of the lower reservoir.

METHODS AND MATERIALS

Seventeen stations were selected for study. Thirteen were located in the lower reservoir and four were located in the upper reservoir above the haulage road.

Three artificial substrate samplers were placed at each station. The upper sampler was suspended at a depth of 0.61 meters, the middle sampler at a depth determined to be one-half of the total depth and the lower sampler at 0.61 meters from the bottom. In order to provide an identical substrate at each sampling location, a modified multi-plate sampler was employed in the study (Hester and Dendy, 1962). Plate orientation was kept constant each time the samplers were assembled to prevent any possible sampling bias (Harrold, 1978). The total exposed area of the sampler was 0.185 square meters.

With the exception of January, 1982, when weather conditions prevented access to the reservoir, samples were collected at approximately 30 day intervals from July, 1981 through June, 1982. Organisms were separated from debris and sediments by means of Wildco Model 190 No. 30 mesh sieve. They were then preserved in 90 percent alcohol and identified using taxanomic keys by Ross (1944), Burks (1953), Pennak (1978), Usinger (1956), Johannsen (1934, 1935, 1937, 1937a), Curry (1961) and Mason (1973).

Species diversity was determined by using an equation based on the information theory equation of Shannon and Weaver (1963). This function is:

$$\bar{H} = 3.3219 \left(\log_{10} N - \frac{1}{N} \Sigma\, n_i \log_{10} n_i\right)$$

where N = total number of individuals
n_i = number of individuals per i^{th} species
3.3219 = conversion factor from $\log_{10}$ to $\log_2$

Calculations were made on a Radio Shack TRS-80 Model III and a Cyber 170 Computer located at the Bradley University Computer Center.

In order to summarize the data, the seventeen stations were divided into zones on the basis of similar temperatures: Zone I (Stations 1 through 4); Zone II (Stations 5 through 8); Zone III (Stations 9, 12, 13 and 14); Zone IV (Stations 15 through 17) and Zone V (Stations 10 and 11). Bathymetric distributions were based on samples which were taken at the same depth or within the same range of depths.

RESULTS AND DISCUSSION

Temperature and Dissolved Oxygen

Average temperatures from both the upper and lower reservoir ranged from 20°C at Station 4, to 33°C at Station 10 in the discharge arm (Fig. 2). Elevated temperatures were consistently observed throughout Zone III, where the heated effluent enters the main body of the reservoir.

Temperature and dissolved oxygen profiles were used to determine the position of the thermocline and the occurrence of overturns. Throughout July and August, the thermocline occurred between six and nine meters. The fall overturn began during October and was completed by January. Temperature and dissolved oxygen was constant throughout the water column until March. The hypolimnion was reestablished below nine meters during June.

Macroinvertebrates

A total of 34,139 macroinvertebrates representing 57 species were collected during the study. Twenty-five of the species were tendipedid larvae with the members of this family contributing 84.2 percent of all individuals. The remaining 16.8 per-

cent were represented by Nematomorpha, Annelida, Amphipoda, Gastropoda, Ephemeroptera, Odonata, Hemiptera, Trichoptera, Coleoptera and two other Dipteran families, Culicidae and Heleidae. One species of Tendipedidae, *G. lobiferus*, constituted 56.6 percent of the total number of individuals (Table 1).

Tendipedids dominated the species composition at every station ranging from 55 percent at Station 5 to 99 percent at Station 11. At Station 10, which is adjacent to the warm water effluent, 98 percent of all organisms were tendipedids. Three species of Tendipedidae, *G. lobiferus*, *G. senilis* and *Dicrotendipes nervosus* were most numerous among this family and all three are known for their wide range of temperature tolerance (Beck, 1977). With few exceptions, *G. lobiferus* was the most abundant species at every station and was found in all samples where organisms were present. In the discharge area, however, *G. senilis* increased in abundance while *D. nervosus* numbers decreased.

As a percent of the total number of organisms collected, the Tendipedidae accounted for 49 percent in June and 100 percent in February. During every sampling period, either *G. lobiferus* or *G. senilis* was the dominant species present. Over 65 percent of all *G. lobiferus* occurred during July. The abundance of this single species is reflected in the increased number of individuals per m^2 during July and September, which corresponds to their expected pattern of emergence and repopulation (Iovino and Miner, 1970).

Two species of Tendipedidae appeared in the dominant species composition only during winter. *Dicrotendipes modestus* was present throughout the study, but only in winter was it encountered in significant numbers. *Cricotopus bicinctus* was not present at any time except winter. According to Iovino and Miner (1970), *C. bicinctus* has a high dissolved oxygen requirement. It was most abundant when high levels of dissolved oxygen were recorded.

In general, the species encountered in this study were typical of those indigenous to the Central Illinois River Basin and other Central Illinois reservoirs. Notably absent in this study were the large populations of clams and oligochaetes present in Peoria Lake (Richardson, 1921, 1921a, 1924, 1925 and 1928) and the chaoborids which are a dominant taxa in both Lake Carlyle and Lake Shelbyville (Dufford, Swadener and Waite, 1976 and 1977; Brigham, 1973, 1974, 1975 and 1976). However, these benthic species do not typically colonize multi-plate samplers and are more frequently encountered in dredge samples.

Macroinvertebrates collected from other thermally impacted waterways closely resembled populations encountered at Duck Creek Reservoir. At Baldwin Lake, communities sampled in the discharge area were dominated by *G. lobiferus* and *D. nervosus* (Parkin and Stahl, 1981). However, these authors also report that these species showed a preference for the Hester-Dendy sampler and were less common in dredge samples taken in the same area. Benda and Profitt (1974) found *G. lobiferus* the most abundant invertebrate collected near thermal discharges into the White River.

The number of organisms encountered varied substantially with the depth of the sampler and ranged from 0 to 8,033 individuals per m^2. Mean values for samples taken at a depth of 0.61 meters ranged from 147 individuals per m^2 at Station 13, to 1,412 individuals per m^2 at Station 1 (Fig. 3). Abundance was significantly reduced throughout the thermally influenced zones; however, Station 11 in the discharge arm had the highest mean number of individuals per m^2 within the lower reservoir.

The range in abundance of macroinvertebrates per m^2 is consistent with those found in similar studies in Illinois. In Peoria lake, Richardson (1925), found 844 to 1,684 individuals per m^2 and in 1928, 192 to 5,634 individuals per m^2 were present. In Lake Sangcris, the range was 57 to 5,028 individuals per m^2 (Webb, 1981), while at Baldwin Lake, the mean was 32 individuals per m^2 in the heated areas and 1,082 individuals per m^2 in unheated areas (Parkin and Stahl, 1981).

The Shannon-Weaver function has been used to illustrate the effect of environment stress by reflecting changes in community structure (Wilhm, 1967; Wilhm and Dorris, 1966; Mathis and Dorris, 1967; Mathis, 1968). $\overline{H}$ values ranged from 2.3 at Station 5 to 0.7 at Station 10 (Fig. 3). The highest values for $\overline{H}$ occurred at Stations 1 through 5, while in areas where the highest water temperatures occurred, reduced $\overline{H}$ values reflected the presence of a few temperature tolerant species.

Seasonal variation in $\overline{H}$ ranged from 0.6 in February (Day 50) to 2.1 in August (Day 250) (Fig. 4). In general, $\overline{H}$ decreased steadily with falling temperatures and increased as temperatures began to rise. In addition to changes in community structure induced by seasonal temperature variation, $\overline{H}$ was also influenced by seasonal reproductive patterns of dominant species.

When all samplers were considered and numbers of individuals were grouped according to similar sampling depths, the number of macroinvertebrates was highest between two and four meters, averaging 789 individuals per m^2. The lowest numbers were found between 16 and 18 meters where only one individual per m^2 was present. The most significant decline in abundance was between six and ten meters. This depth corresponds to the thermocline. Below ten meters, organisms were rarely encountered (Fig. 5).

As a percent of the total number of organisms collected, the Tendipedidae were dominant at all depths, ranging from 71 percent to 100 percent of all individuals. Below eight meters, *G. lobiferus* and *G. senilis* were most numerous. Both of these species have a low dissolved oxygen requirement and are considered by some to be facultative anaerobic (Beck, 1977).

Community structure, as assessed by $\overline{H}$, paralleled the bathymetric distribution of individuals (Fig. 5). Within the thermocline, $\overline{H}$ was dramatically reduced. An $\overline{H}$ value of 1.7 was determined for both the two to four meter and four to six meter ranges. $\overline{H}$ was zero between 16 and 18 meters, where either *G. lobiferus* or *G. senilis* was the only species found.

SUMMARY

Hester-Dendy samplers were used over a twelve month period to determine the effects of thermal enrichment on the community structure of macroinvertebrates in Duck Creek Reservoir. Fifty-seven species and 34,139 individuals were collected during the study. Twenty-five of the species and 84 percent of all individuals were tendipedid dipterans. The remaining 16 percent of the taxa were represented by Nematomorpha, Annelida, Amphipoda, Gastropoda, Ephemeroptera, Odonata, Hemiptera, Trichoptera, Coleoptera, and Diptera families Heleidae and Culicidae. With few exceptions, species composition and abundance of organisms were consistent with those reported in other thermally impacted reservoirs.

The Tendipedidae were the dominant organisms at each station, at all depths and during every season. *Glyptotendipes lobiferus* constituted 57 percent of all organisms collected, while *G. senilis* comprised 13 percent of the total number. Both species

are known to be tolerant of extreme temperatures and both were found abundantly in the discharge area. *Pentaneura monilis,* a temperature tolerant tanypod whose abundance increased with temperature, appeared to have replaced *Cyrnellus marginalis* near the outfall.

The average number of individuals per m^2 varied considerably between the upper and lower reservoir. In general, density was significantly greater at stations in the upper reservoir. The highest density in the lower reservoir was at Station 11, where water temperatures were moderately influenced by the effluent.

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Table 1. Relative abundance of macroinvertebrates collected from upper and lower Duck Creek Reservoir.

Species	Number Collected	Relative Abundance	Location by Zone
Glyptotendipes lobiferus	19,315	57%	I,II,III,IV,V
G. senilis	4,289	13%	I,II,III,IV,V
Dicrotendipes nervosus	3,955	12%	I,II,III,IV,V
Cyrnellus marginalis	2,543	8%	I,II,III,IV,V
Pentaneura monilis	1,179	4%	I,II,III,IV,V
Caenis sp.	1,082	3%	I,II,III,IV,V
Chironomus tentans	404	1%	I,II,III,IV,V
Endochironomus nigricans	213	1%	I,II,III,IV,V
Dicrotendipes modestus	181		I,II,III,IV,V
Harnishia abortiva	165		I,II,III
Argia sedula	132		I,II,III,IV,V
Limnodrilus sp.	106		I,IV
Hyalella azteca	68		I,II,III
Gordius sp.	66		I,II,IV,V
Cricotopus bicinctus	62		I,II,II,IV,V
Argia sp. a	45		I,II,III,IV,V
A. emma	31		I,II,III,IV,V
Potamyia flava	31		V
Polypedilium flavus	31		I,II,III,IV,V
Pentaneura flavifrons	28		I,II,III,V
Hydropsyche orris	25		II,V
Bezzia varicolor	21		I,II,III,V
Diamesa sp.	20		I,II,III,V
Argia vivida	17		I,II
Phaenospectra obediens	15		I,II,III
Enallagma praevarium	12		I,II,IV,V
Agraylea multipunctata	11		I,II
Tribelos sp.	10		II,III,V
Paralauterborniells sp.	9		I,II,V
Physa sp.	9		II,V
Palpomyia tibialis	8		I,II
Psectrocladius simulans	8		I,II,III,V
Dineutus sp.	8		I,II
Chaoborus punctipennis	7		I,II,V
Parachironomus monochromus	6		I,II
Cryptochironomus sp.	6		I,II
Enallagma sp.a	6		I,II

Table 1 (cont.)

Species	Number Collected	Relative Abundance	Location by Zone
Chironomus attenuatus	6		I
Cricotopus fugax	5		I,II
Ephemerella deficiens	4		I
Orthocladius sp.	4		I,IV
Enallagma carunculatum	4		II,IV,V
Procladius bellus	3		II
Probezzia sp. a	3		I,II,III
Tanypus stellatus	2		III
Gyretes sp.	2		I
Baetis sp.	2		I
Hexagenia limbata	1		II
Ishnura barberi	1		V
Chromagrion conditum	1		I
Lethocerus americanus	1		II
Coelotanypus concinnus	1		I
Einfeldia sp.	1		I
Chaoborus sp. a	1		II
Chaoborus rotundifolia	1		I
Probezzia copiosa	1		I
Ferrissia sp.	1		I
TOTAL NUMBER OF SPECIES	TOTAL NUMBER OF INDIVIDUALS		
57	34,139		

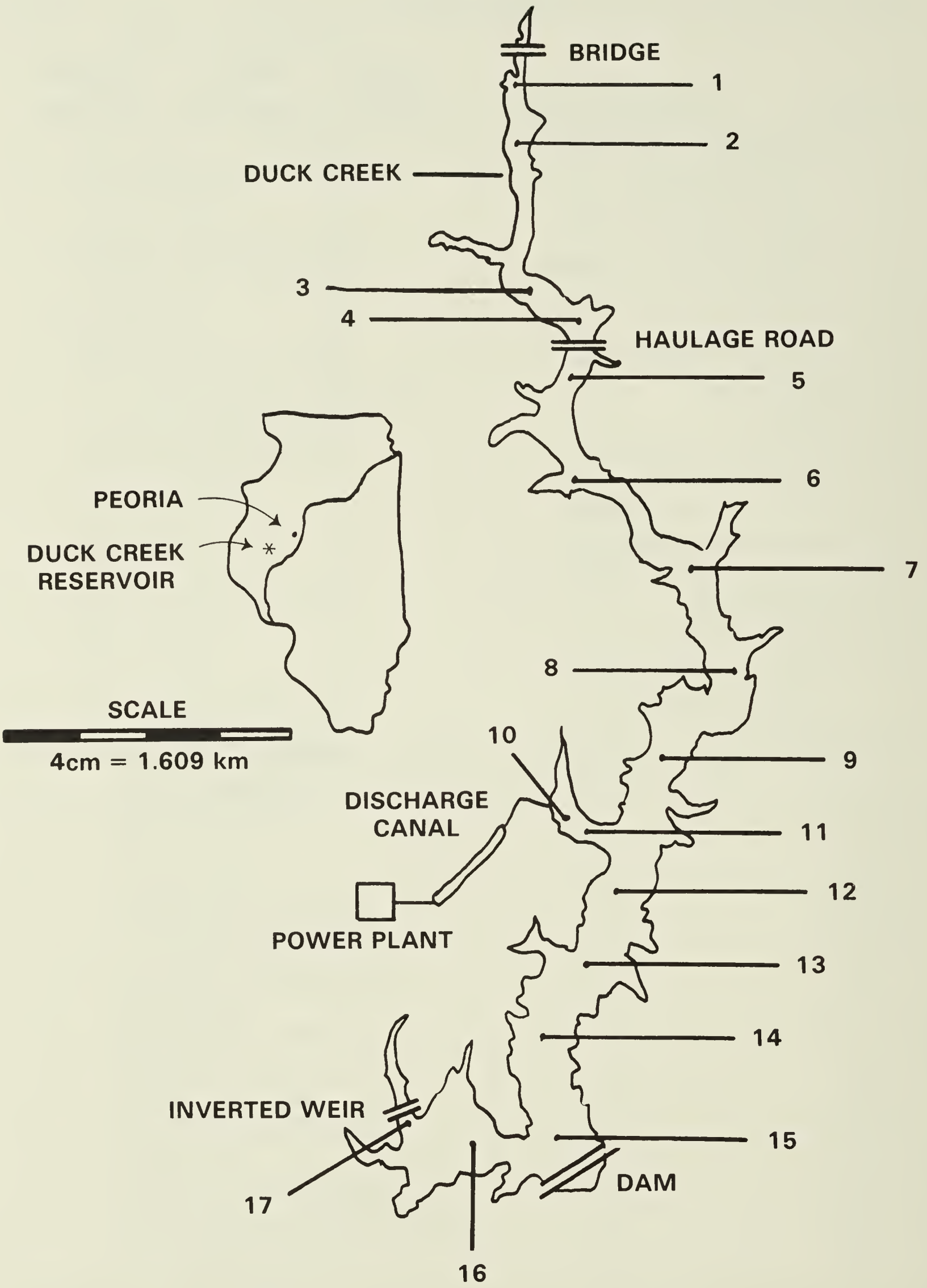

Fig. 1. MAP OF DUCK CREEK RESERVOIR SAMPLING STATIONS AND TEMPERATURE ZONES (Zone I-Stations 1-4; Zone II-Stations 5-8; Zone III-Stations 9, 12, 13 and 14; Zone IV-Stations 15-17; and Zone V-Stations 10 and 11).

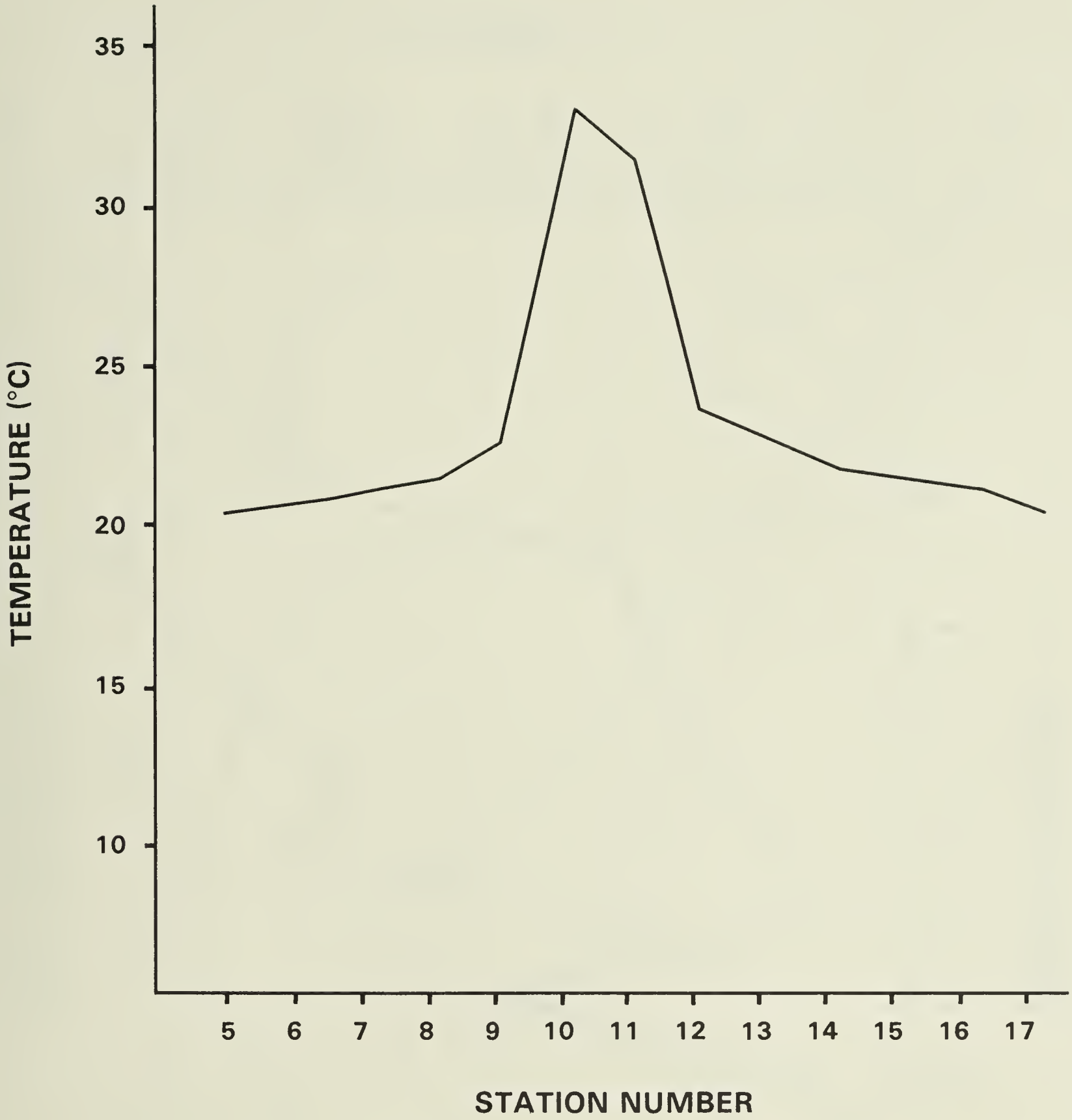

Fig. 2. MEAN TEMPERATURE FOR STATIONS IN LOWER DUCK CREEK RESERVOIR DURING 1981 AND 1982 AT A DEPTH OF 0.61 METERS.

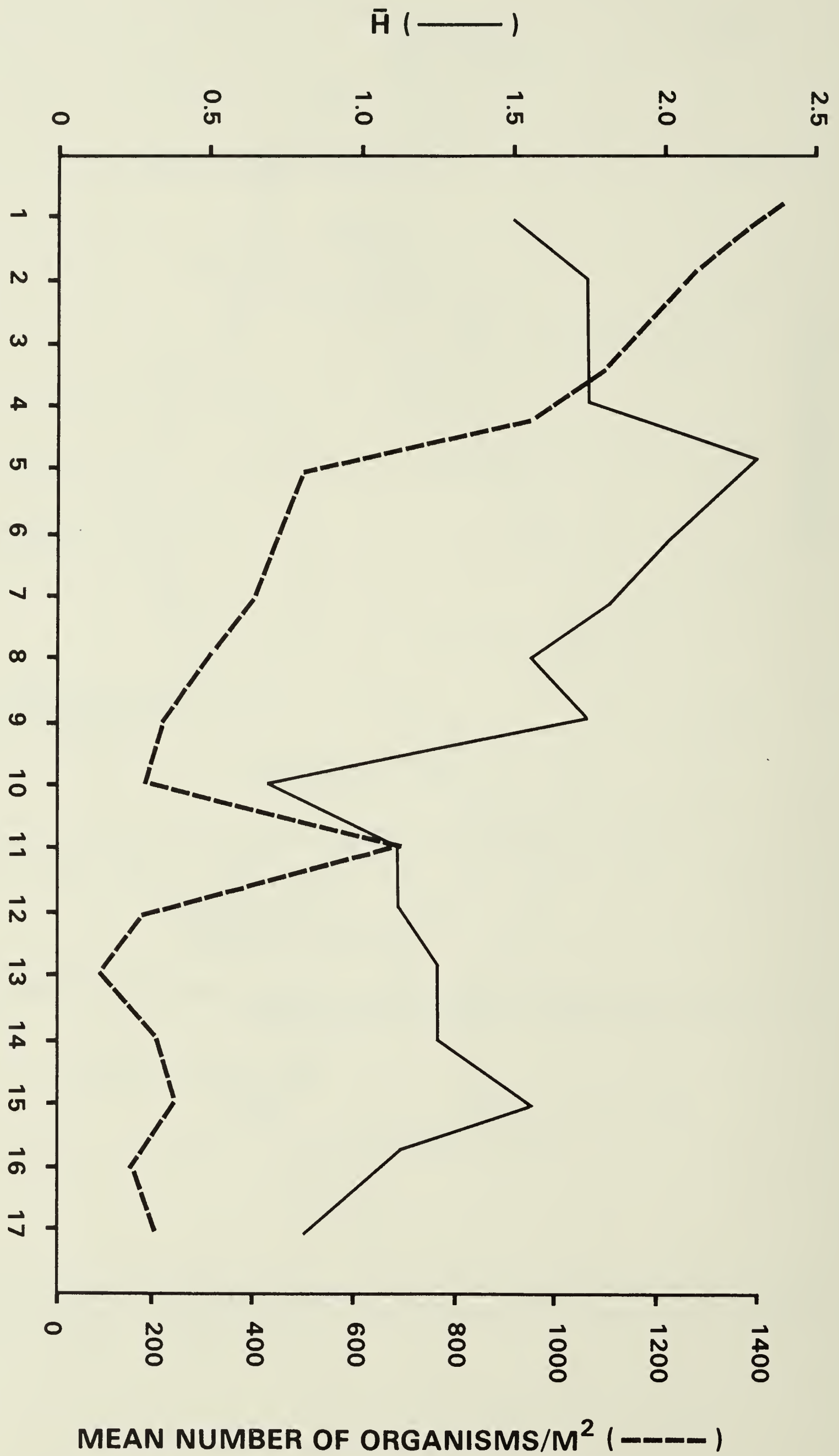

Fig. 3. MEAN NUMBER OF ORGANISMS/M^2 AND $\overline{H}$ FOR SAMPLES TAKEN AT A DEPTH OF 0.61 METERS.

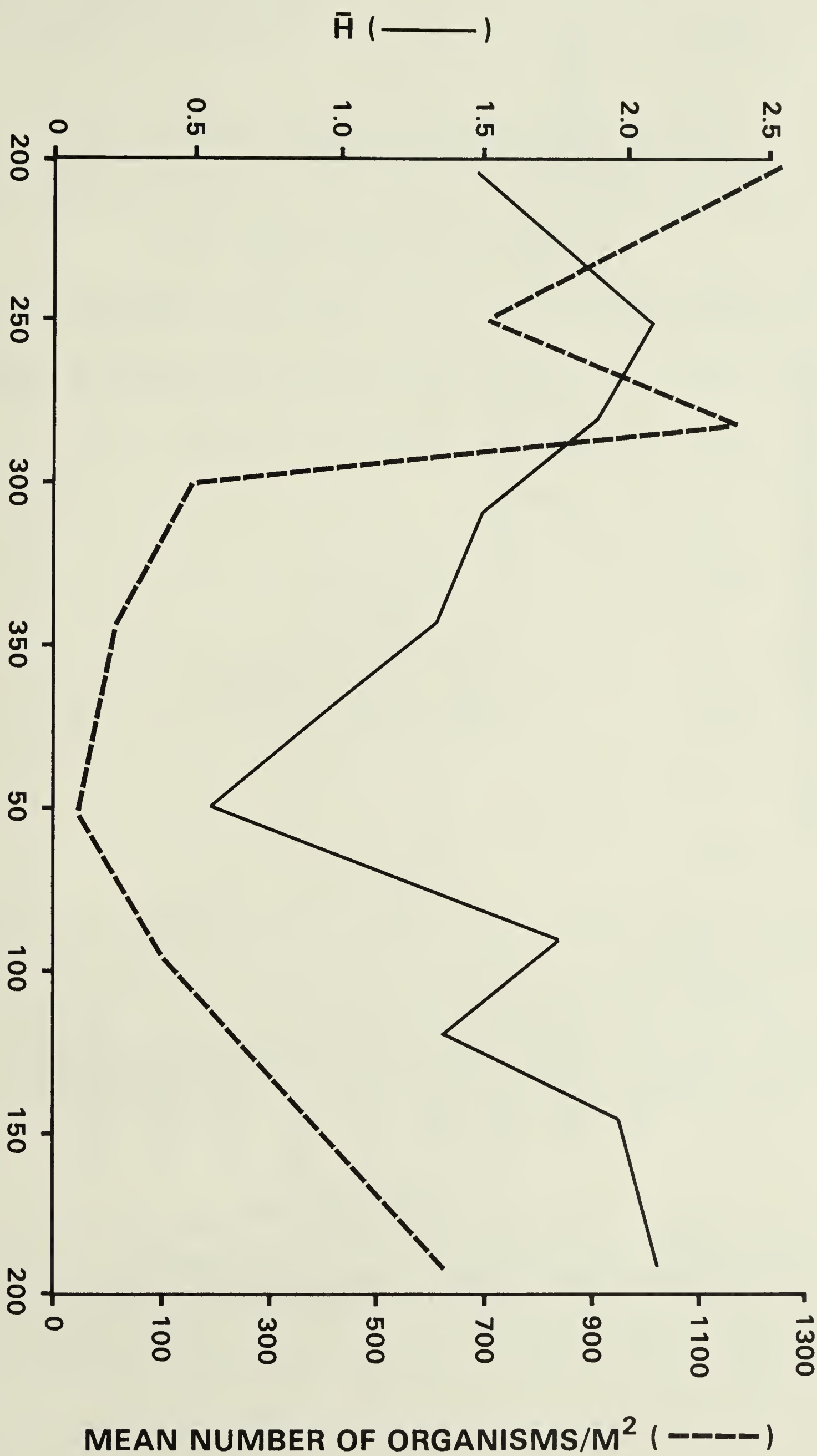

Fig. 4. SEASONAL VARIATION IN NUMBERS OF ORGANISMS/M^2 AND $\overline{H}$ FOR ALL SAMPLES TAKEN AT A DEPTH OF 0.61 METERS.

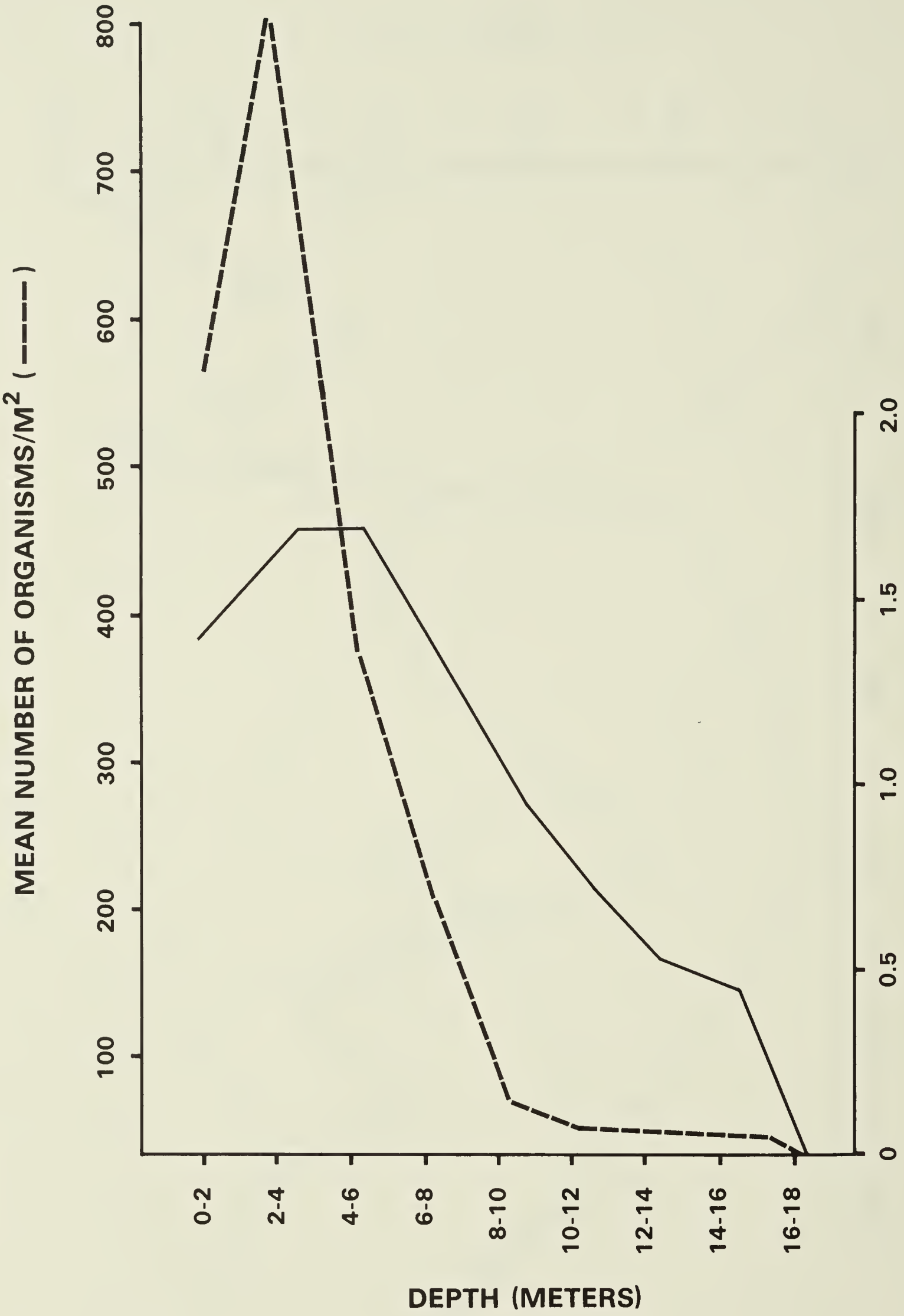

Fig. 5. BATHYMETRIC DISTRIBUTION OF ORGANISMS/M^2 AND $\overline{H}$.

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PIONEER COLONIZATION AND INTERACTION OF PHOTOSYNTHETIC AND HETEROTROPHIC MICROORGANISMS ON AN ARTIFICIAL SUBSTRATE OF POLYURETHANE FOAM IN E. J. BECK LAKE, ILLINOIS

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ABSTRACT

The accrual of pioneer microbial inhabitants on an artificial substrate of polyurethane foam in a freshwater ecosystem during a 22 day sampling period was an approximately linear event. Compared to the fast and sometimes fluctuating arrival of photosynthetic algae, the colonization by protozoa was slow and steady. However, there was greater diversity for the photosynthetic algae than for the heterotrophic protozoa. Artificial substrates harvested toward the end of the sampling period yielded more phylogenetically advanced organisms and perhaps signified a transition to a more complex stage in the colonization sequence.

INTRODUCTION

Use of artificial substrates to monitor aquatic conditions has increased over recent years (Weitzel, 1979; Henebry and Cairns, 1980; Cairns, 1982). The colonization process on artificial substrates, since it mimics similar naturally occurring processes, serves as an "island model" for studying the immigration rate and interaction of colonists on natural substrates in the aquatic environment (Cairns, Kuhn, and Plafkin, 1979; Cairns and Henebry, 1982; Osman, 1982). Synthetic polyurethane

foam (PF) is widely used as a substrate due to its superior collecting ability and low cost (Bamforth, 1982). This investigation examined the initial colonization process by charting the accumulation of some pioneer photosynthetic algae and heterotrophic protozoa on PF substrates for selected days during a 22 day period. Water surrounding the substrates was also sampled to provide an indication of the number and diversity of microorganisms immediately available for substrate colonization.

MATERIALS AND METHODS

E.J. Beck Lake, located near Des Plaines, Illinois, occupies approximately 38 acres and is managed by the Forest Preserve District of Cook County as a recreational area. In 1958, the lake was excavated to a depth of 23 feet to provide a source of fill for an interstate highway located immediately to the east (Forest Preserve bulletin, 1971). The water sources for the lake are ground water, highway run-off, and rain. The lake maintains a stocked population of fish.

The sampling site is located in the northwest corner of the lake. This area has a relatively calm surface due to screening by tall trees and other vegetation lining the shore. A dense growth of *Typha* along the shoreline limited the access to the area and diminished the likelihood of vandalism.

Sampling was performed during late October and early November of 1983. The artificial substrates were PF blocks measuring 5.0 by 6.5 by 7.5 cm (Cairns and Ruthven, 1970). The blocks were tied and tightly cinched in the middle with a piece of string; long ends were left to allow for attachment of an anchor and marker float (Bamforth, 1982). Each PF substrate was anchored with a stone approximately 10 lbs in weight. The stone was placed in a plastic bag and tied securely to one end of the string. These anchors were attached 60 cm from the PF substrates. This method assured a consistent positioning of the naturally buoyant PF substrates from the lake bottom. The distance of the PF substrates from the surface varied as the lake level changed during the sampling period: the distance below the surface was never less than 10 cm nor more than 20 cm. The other end of the string was attached to a styrofoam fragment which acted as a floating marker. Eight of these devices were deposited in a line 9 to 12 m from the shore and 3 m apart.

On each day of sampling, air and water temperatures were recorded using a "Testrite" brand thermometer (Japanese Instrument Co.). Water pH was tested with pHydrion strips (Micro Essential Lab., N.Y.). Water surrounding the PF substrates was sampled by plunging a capped 200 ml sample bottle into the water adjacent to the PF substrate to be harvested. When the bottle reached the depth of the substrate, the cap was removed allowing the bottle to fill. The cap was then replaced underwater. Once these procedures were completed, the PF substrate was harvested. Upon removal from the water, the substrate was squeezed by hand until approximately 100 mls of fluid was collected in a 200 ml bottle. All samples were examined microscopically within the next hour.

In the laboratory, the sample bottles were shaken gently by hand. A 0.25 ml aliquot was removed from each bottle and diluted with equal amounts of 1% methyl cellulose to aid in observation. The enumeration of species was performed at 100X using an ocular lens fitted with a Whipple grid. Counts were adjusted for dilution. Organisms were identified with the aid of standard references (Ward and Whipple, 1959; Prescott, 1978; Jahn, Bovee, and Jahn, 1979).

The determination of the number of organisms per milliliter was accomplished by

using the "Lackey Drop Microtransect Counting Method" as modified below (Lackey, 1938; *Standard Methods*, 1976, p. 1027). Statistical treatment of the data involved the establishment of confidence intervals based on 1 standard error or deviation (Snedecor and Cochran, 1956, chapters 2, 3, and 17; Mendenhall, 1967, chapter 8).

$$\frac{C \times TA}{A \times S \times V} = \text{Number of organisms / milliliter}$$

where:

C = actual number of organisms counted,

TA = total area under coverslip (22 by 22 mm = 484 mm^2 times the number of drops of sample examined),

A = area counted in microscope field at 100X; using the Whipple grid, 42 squares were counted in each field; each square is 200 μm on a side, so the entire field of 42 squares is 200 by 200 by 42 = $1.68 \times 10^6 \mu m^2$ since 1 mm^2 = $1 \times 10^6 \mu m^2$,

S = number of fields of 42 squares each that were counted; up to 60 such fields were examined for each sample,

V = total volume in mls examined; 1 drop = 0.05 ml.

RESULTS

Environmental monitoring was performed at the time the samples were taken and indicated an air temperature range of 6° to 13°C, a water temperature range of 9° to 10°C and a consistent water pH of 6.5.

Results of microbial sampling appear in Table 1. Figures 1 and 2 represent the numbers of organisms found at each sampling over the period of the study. Identification of organisms collected on the PF substrates and from the surrounding water yielded a total of 14 genera representing 11 families and 2 kingdoms (Table 1). Only 1 genus (*Spirogyra*) present in the surrounding water did not appear on the PF substrates during the sampling period. Although the majority of collected organisms were photosynthetic, considerable variation existed in the families and genera present. Most photosynthetic organisms were from the Family Naviculaceae, with *Navicula* being the most prevalent. As time progressed, the filamentous blue-green algae such as *Oscillatoria* and *Anabaena*, and elongate diatoms such as *Fragilaria* and *Synedra* increased in number. This occurrence was noted particularly after day 9.

Natural vegetational substrates (*Typha*) within 9 m of the sampling area yielded additional types of organisms including 1 genus from the Kingdom Monera, 4 genera from the Kingdom Protoctista, and 2 genera from the Kingdom Animalia. These data are not included in Table 1 nor are they reflected in the totals represented by Figures 1 and 2.

Figure 1 shows that the colonization of organisms on the PF substrates over the 22 day sampling period was approximately linear. It increased with each sample reaching a level nearly 12 times the average number of organisms present in the surrounding water during the same period of time. There was a sharp contrast between the relatively stable number of organisms present in the surrounding water (an average of 3.29 over the sampling period) and the progressive increase to 9 genera of organisms present on the PF substrates. This nearly threefold increase in diversity was largely the result of colonization by photosynthetic organisms (Fig. 2). At the end of the sampling period, autotrophic organisms were 20 times more numer-

ous than the heterotrophic organisms found on the same PF substrate. Moreover, the number of photosynthetic genera (8) found on the PF substrate for day 22 was nearly 5 times greater than the heterotrophic ones (average, 1.75) that colonized the substrates over the entire period of sampling.

DISCUSSION

The upward trend in the accrual of photosynthetic organisms on the PF substrates shown in Figures 1 and 2 corresponds to the initial "noninteractive" colonization stage described by Cairns and Henebry (1982). Since no plateau is reached during this period, it is assumed that the final equilibrium of the number and diversity of organisms was not reached (Cairns *et al.*, 1979).

The inhabitants present probably are pioneers comprising part of the initial colonization stage. The 7 genera found on nearby natural substrates and the 1 genus present in the surrounding water did not appear on the PF substrates. This suggests to us that additional colonization would likely occur given more time. According to Cairns *et al.* (1979), this happens because the natural environment contains a "source pool" of potential colonists.

Colonization of PF substrates by heterotrophs was a conservative event in comparison to colonization by photosynthetic organisms. Figure 2 shows only a slow rate of increase of heterotrophic organisms, both in number and diversity after day 3. This compares favorably with the results of Cairns *et al.* (1979) and Cairns and Henebry (1982) where a colonization equilibrium is reached within 3 days in similar aquatic environments. We believe it is likely that an equilibrium has occurred for the heterotrophs because there is a decrease in the number and diversity of those organisms recovered at day 22. However, further testing involving longer time periods would be required to confirm this.

The decrease in the number of photosynthetic organisms on day 5 (Fig. 2) was most likely due to a heavy rain on day 4 which caused the lake level to rise with accompanying disturbances of surface water. Evidently, these disturbances did not affect the variety of organisms available for colonization since the progressive increase in diversity continued for these organisms. These events also appeared to have little effect on the number and diversity of the heterotrophs found on the PF substrate for day 5 (Fig. 2).

Cairns and Ruthven (1970) pointed out that such "fluctuations" could be merely the result of sampling and counting errors. Care was taken in this study to minimize these problems; the fluctuations found on days 5 and 22 did not adversely alter the overall colonization trends and were not statistically significant as reflected by the standard error bars in Figs. 1 and 2.

The diversity of organisms colonizing the PF substrates after day 9 widened to include complex filamentous and elongate varieties of microbes. The accumulation of more advanced photosynthetic organisms increases the surface area on the PF substrates thus making it possible for even greater amounts of debris and other organisms from the surrounding water to collect on the substrates. Both autotrophs and heterotrophs eventually benefit from the greater diversity and accumulated debris since havens are created for additional subsequent colonization. The early autotrophic colonists prepare and modify the PF substrate habitat for later arriving heterotrophic protozoa (Cairns *et al.*, 1979). With increasing colonization, more abundant food sources like bacteria and algae become available to the heteroptrophs (Bam-

forth, 1982). This stage of colonization is a necessary prelude to the next developmental stage where later immigrant species interact with the already established microcommunity (Cairns and Henebry, 1982).

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Table 1. Taxonomy, source and trophic categories of collected organisms.*

Kingdom	Family	Genus	Source	Trophic Category
Monera	Nostocaceae	*Anabaena*	W S	P
	Oscillatoriaceae	*Oscillatoria*	S	P
Protoctista	Naviculaceae	*Navicula*	W S	P
		Pinnularia	W S	P
		Gyrosigma	W S	P
	Fragilariaceae	*Synedra*	S	P
		Fragilaria	S	P
	Coscinodiscaceae	*Cyclotella*	S	P
	Hydrodictyaceae	*Pediastrum*	S	P
	Volvocaceae	*Volvox*	W S	P
	Zygnemataceae	*Spirogyra*	W	P
	Amphileptidae	*Litonotus*	S	H
	Bodonidae	*Bodo*	W S	H
	Difflugiidae	*Difflugia*	W S	H

*The taxonomy follows Margulis and Schwartz (1982), Prescott (1978), Corliss (1979), and Jahn, Bovee, and Jahn (1979). The sources of collected organisms are identified by W (surrounding water) and S (PF substrate). Trophic categories are identified by P (photosynthetic) and H (heterotrophic).

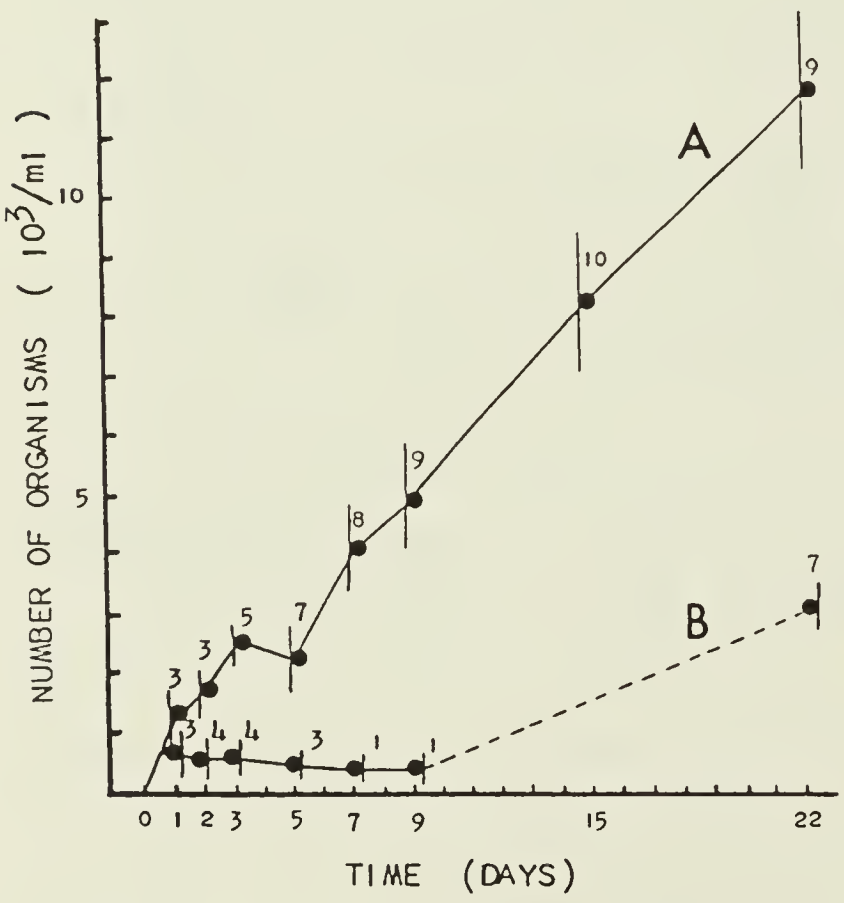

Fig. 1. Combined photosynthetic and heterotrophic colonization of the PF substrates (A) compared to the numbers of these organisms in the surrounding water (B). Since water data was unavailable for day 15, an extrapolation between days 9 and 22 is indicated by a dashed line. Numerals appearing above the data points refer to the daily total of genera represented by the plotted numerical totals. Vertical bars represent one standard error of the mean.

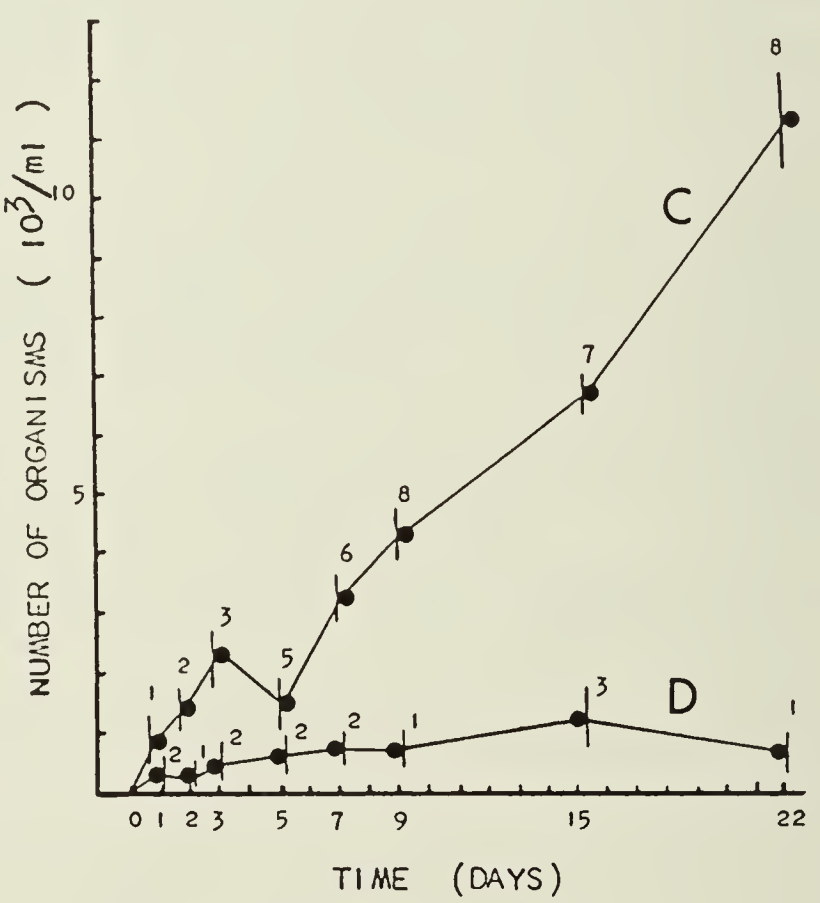

Fig. 2. The colonization of PF substrates by photosynthetic (C) vs. heterotrophic organisms (D). Numbers above data points and bars are as in Fig. 1.

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BIRD USE OF WETLANDS CREATED BY SURFACE MINING

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ABSTRACT

The use of wetland habitats remaining after surface-mining in west-central Illinois by summer resident birds was documented during 1979-1980 and 1982-1984 while studying giant Canada geese on the area. Confirmed nesting species were giant Canada goose, mallard, black duck, blue-winged teal, wood duck, hooded merganser, mute swan, American coot, common moorhen, pied-billed grebe, killdeer, and spotted sandpiper. Suspected nesting species were lesser scaup, northern pintail, American bittern, and green-backed heron. Other summer visitors were green-winged teal, redhead, common merganser, great blue heron, great egret, cattle egret, sora, and king rail. It was concluded that wetlands created by surface-mining made a valuable contribution in terms of avian habitat in west-central Illinois.

INTRODUCTION

Water areas resulting from surface mining for coal often have been regarded as a liability, being characterized as acidic, low in fertility, and having poor fish production (Lewis and Peters 1954, Riley 1960, Stockinger and Hays 1960, Riley 1965, Campbell et al. 1965, Campbell and Lind 1969, Lind and Campbell 1970, Gash and Bass 1973, Wilbert 1974, and others). However, there is evidence that in many situations surface mine waters provide quality aquatic environments (Christy et al. 1979, Rosso 1979, Streeter et al. 1979, Konik 1980, Coss 1981, Klimstra and Nawrot 1982). Little attention has been given to the potential value of wetlands on surface mines as habitat for wetland bird species. Sandusky (1978) documented use of surface mine ponds in southern Illinois by 3 nesting duck species and Perkins (1981) reported that giant Canada geese (*Branta canadensis maxima*) introduced on sur-

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face mined lands in west-central Illinois were thriving. This report documents use of wetland habitats on surface mines in west-central Illinois by summer resident birds and demonstrates the potential value of wetlands development as a reclamation alternative.

STUDY AREA AND METHODS

The 4-county study area included 17,783 ha of surface mined land in Fulton County, 8,362 ha in Knox County, 1,137 ha in Peoria County, and 1,083 ha in Henry County (Fig. 1). Nearly 60% of the study area was mined prior to enactment of the Open Cut Land Reclamation Act of 1962 and was not subject to reclamation requirements (Klimstra and Thornburg 1982). However, certain areas with high quality soils were voluntarily reclaimed by minimal strike-off and some grading. Post-law lands exhibited a range of reclamation intensity from minimal strike-off to grading to approximate original contour, corresponding to increasing regulatory constraints imposed by changes in Illinois legislation during 1962-1976 (Klimstra and Thornburg 1982).

Forage production and grazing were the most common land uses; principal vegetative species included brome (*Bromus* spp), sweet clover (*Melilotus* spp), fescue (*Festuca* spp), and alfalfa (*Medicago* spp). Forested tracts of volunteer species were locally common, especially on pre-law lands. Row-cropping was not prevalent except on the most recently reclaimed tracts, but represented the major surrounding land use.

Wetlands and deepwater habitats totalling 2,244 ha (Haynes and Klimstra 1975, unpubl. coal company data) were highly variable ranging from small seasonally flooded basins to large deep lakes. Problem waters existed only in very isolated settings where runoff was received from mine wastes and were not due to weathering of overburden material. Water quality was generally good, supporting a diversity of aquatic macrophytes and invertebrates. Konik (1980) identified 71 invertebrate taxa in 2 Fulton County lakes and found abundant aquatic vegetation at depths up to 5 m; muskgrass (*Chara* spp), pondweeds (*Potamogeton* spp), and southern naiad (*Najas quadalupensis*) were the principal species. Other locally abundant aquatic plants included waterweed (*Elodea* spp), watermilfoil (*Myriophyllum* spp), coontail (*Ceratophyllum demersum*), and American lotus (*Nelumbo lutea*). Emergent species, mainly cattails (*Typha latifolia, T. angustifolia*) and softstem bulrush (*Scirpus validus*), often dominated shorelines with suitable slopes. Ephemeral basins and areas of moist soil were dominated by communities of nutgrasses (*Cyperus* spp), spikerushes (*Eleocharis* spp), sedges (*Carex* spp), rushes (*Juncus* spp), and a wide array of pioneering annuals.

The physical characteristics of water bodies were a function of the method of coal extraction and the degree of reclamation. Bucket-wheel excavation produced smaller, less uniform spoilbanks than did shovel and dragline. When inundated, the former yielded areas with very irregular shorelines and numerous islands, while the latter often resulted in a series of parallel impoundments with more uniform shorelines and fewer islands; both were characterized by a diverse bottom topography. Boxcut and incline impoundments were often deep, steep-sided, fairly uniform, and offered only a very narrow littoral zone.

Data were collected during 1979-1980 and 1982-1984 while studying giant Canade geese introduced into the study area in 1969. Observations are of those wet-

land bird species believed to be summer residents, and do not include those known to frequent the area during migrations. Records were kept for species within 5 orders: Anseriformes (ducks, geese, and swans), Ciconiiformes (herons, bitterns, and egrets), Podicipediformes (grebes), Gruiformes (rails and coots), and Charadriiformes (shorebirds). Based on the nature of the observations, species were placed in one of 3 categories. *Confirmed nesting species* were those for which either nests or broods were observed. *Suspected nesting species* exhibited behavior indicating nesting activities or frequenting a given location; no nests or broods were located. *Other summer visitors* were species recorded during the summer but no observations indicated nesting activity. Bird species names follow the latest classification of the American Ornithologists' Union (1983).

RESULTS AND DISCUSSION

Twelve species were confirmed as nesting, 4 as suspected nesting, and 8 as summer visitors (Table 1). Individual species accounts follow with observations on their use of wetland and adjacent upland habitats.

Confirmed Nesting Species

Canada Goose (*Branta canadensis maxima*). — Perkins (1981) detailed the status and breeding biology of the giant Canada goose population estimated to be over 3,000 prior to production in 1980. Of 242 nests monitored during 1979 and 1980, 74.8% were successful; clutch size averaged 5.7. Mean brood size at hatching was 5.2 both years. Not only were island nest sites more preferred (83.5%) over those on shore, they were more successful (82.2%) compared to shore nests (37.5%). Sweet clover, grasses,, and broad-leaved weeds, composed the bulk of nest materials. An abundance of relatively safe islands for nesting was a key factor in population productivity. Impounded spoils created by bucket-wheel excavators provided the greater number of desirable island situations.

Mallard (*Anas platyrhynchos*). — Mallards were the most commonly observed nesting ducks. Mean clutch size of 17 nests located during incubation was 9.8 eggs; this was higher than the 9.0 reported by Bellrose (1980) for 5,170 nests. The small sample of nests recorded was restricted to early nests; overall clutch size was probably lower as early clutches have more eggs (Dzubin and Gollop 1972). Although half of the nests located were on islands, such nests were more likely to be found. Mainland nests were in areas of ungrazed grasses 0.5-1.0 m tall. Based on all age classes recorded, mean size of 78 broods was 7.2. Undisturbed broods were most often noted in shallow water with aquatic vegetation.

Black duck (*Anas rubripes*). — No nests and only one brood of the black duck were documented. Its occurrence in west-central Illinois approaches the western and southern limits of its breeding range (Bellrose 1980); and, it is listed as a rare summer resident in Illinois (Bohlen 1978). This species is an ecological equivalent to the mallard in many respects and probably utilizes similar habitats. A few black ducks were released on the study area by the Illinois Department of Conservation, and probably accounted for the observed production.

Blue-winged Teal (*Anas discors*). — One blue-winged teal nest containing 2 eggs was located on 1 June 1979 when the female was observed returning to the site in tall grass, about 100 m from water. The combination of later nest initiation and a tendency to nest far from water (Bellrose 1980) possibly precluded other dis-

coveries. Mean size of 10 broods of all age classes was 5.8; these were most often observed in small shallow ponds with aquatic vegetation. Numerous observations of pairs and lone males indicated this species was much more common than suggested by nest and brood records.

Wood duck (*Aix sponsa*). — Female wood ducks were observed entering nest cavities at 2 locations but nests were not checked. Four broods ($\bar{X}$ = 12 ducklings) were recorded; however, incidental observations were unlikely, due to the tendency of wood ducks to frequent areas of emergent and overhanging woody vegetation. Also, little time was spent on forested tracts of pre-law lands best suited for wood duck nesting.

Hooded Merganser (*Mergus cucullatus*). — Five hooded merganser broods were recorded between 10 May and 13 June 1983 on one area adjacent to the Illinois River in Fulton and Peoria counties (Fig. 1). Few mature trees were present and nesting likely occurred in nearby bottomland forests. Broods probably moved to wetlands on the mined area for more suitable foraging. According to Bellrose (1980), hooded mergansers cannot find adequate food in highly turbid waters. The Illinois River and associated wetlands are generally highly turbid (Bellrose et al. 1979), while mine site waters reflect very low turbidity (Konik 1980).

Mute Swan (*Cygnus olor*). — Several mute swans were introduced into the study area during the early 1970's; successful nests were observed during subsequent years prior to 1979 (Illinois Department of Conservation unpubl. data). Four unsuccessful nests were observed; all were built on platforms of cattail stems anchored among standing cattails.

American Coot (*Fulica americana*). — Two families of coots consisted of 1 adult with 8 young on 2 July 1979, and of 2 adults with 3 young on 27 June 1980. Singles, pairs, and small groups were commonly observed throughout spring and summer on small wetland basins with shorelines dominated by cattail. This wetland type is a preferred nesting habitat of coots (Fredrickson 1977). The American coot is listed as an uncommon summer resident in central Illinois (Bohlen 1978).

Common Moorhen (*Gallinula chloropus*). — The common moorhen (formerly common gallinule), a threatened species in Illinois, has been reported nesting recently in only Cook and Lake counties in extreme northeastern Illinois (Natural Land Institute 1981). Although our studies yielded no nests, a brood of 3 was observed on 6 July 1982. According to Strohmeyer (1977), nesting habitat requirements are similar to those of the American coot.

Pied-billed Grebe (*Podilymbus podiceps*). — Two broods of grebes (2 and 4) were observed on 6 July 1979 at one site in Peoria County. Singles and pairs were observed occasionally on all types of wetlands and deepwater habitats. This species is considered an uncommon summer resident in central Illinois (Bohlen 1978).

Killdeer (*Charadrius vociferus*). — Killdeer, the most common resident shorebird in Illinois (Bohlen 1978) was abundant. Several broods were observed but no count was recorded. The "wing-injury feigning" display of the female was commonly encountered during the summer.

Spotted Sandpiper (*Actitis macularia*). — An uncommon summer resident of central Illinois (Bohlen 1978), spotted sandpipers were rarely observed after spring migration. One nest containing 2 eggs was located on a gravel bar after a female flushed on 25 May 1980, and one flightless young was observed with an adult in 1984. Because of the small inconspicuous nature of these birds, it is possible other nests were present but undetected.

Suspected Nesting Species

Lesser Scaup (*Aythya affinis*). — A pair of lesser scaup was observed five times during 1-16 May 1979 at the same loafing site near a cattail bed on a 6.5 ha permanent lake in Fulton County. A lone male (presumably from the same pair) was observed at the same site 4 times during 18-28 May, indicating the female was incubating nearby. Two similar instances of apparent nesting activity were recorded in 1980. According to Bohlen (1978) the lesser scaup is a rare summer resident in Illinois.

Northern Pintail (*Anas acuta*). — Several sightings of pairs and observation of a group of 6 flightless pintails on 1 July 1980 indicated some nesting probably occurred. A small number of pintails was released on surface mines in the area by the Illinois Department of Conservation. The pintail is considered a rare summer resident in central Illinois (Bohlen 1978).

American Bittern (*Botaurus lentiginosus*). — American bitterns were observed 4 times during 15 May-6 July 1979, 11 times during 19 May-3 July 1980, and were also seen in 1982 and 1983. All sightings occurred at a small permanent pond surrounded by a dense bed of cattails, the characteristic nesting habitat for this species (Bent 1926). Of the 15 observations in 1979 and 1980, 8 were of 1 individual and 7 were of 2 individuals. The "thunder-pumping" performance, a component of the nuptial display (Bent 1926), was observed on 2 occasions. The American bittern is classified as a state endangered species in Illinois (Natural Land Institute 1981).

Green-backed Heron (*Butorides striatus*). — Although no observations of nesting activities by the green-backed heron (formerly green heron) were recorded, individuals were often seen foraging during all times of the day at 2 sites in Fulton County. The frequency and site-fidelity of observations suggested this species probably nested in those localities. Bohlen (1978) classified the green-backed heron a common summer resident in Illinois.

Other Summer Visitors

Observations of single individuals of green-winged teal (*Anas crecca*), redhead (*Aythya americana*), and common merganser (*Mergus merganser*), were recorded occasionally during June and July. Great blue herons (*Ardea herodias*) and great egrets (*Casmerodius albus*) were commonly seen foraging throughout the study area during all years. These colonial nesting birds presumably made feeding flights to the area from a nearby rookery along the Illinois River. Cattle egrets (*Bubulcus ibis*) were occasionally observed during 1982 and 1983. Five soras (*Porzana carolina*) and 2 king rails (*Rallus elegans*) were observed at one site in Knox County in 1979; the rails were flushed from narrow between-spoil depressions dominated by sedges and cattails and lacking open water.

CONCLUSIONS

It is evident that a variety of bird species utilize aquatic areas resulting from surface mining in west-central Illinois. The value of these wetlands as habitat is reflected in the array of requirements of the birds using them. Habitats provide, collectively and individually, safe island nest sites for geese and mallards; expanses of grassy upland areas for duck nesting; a good interspersion of open water, submersed aquatic vegetation, and emergent vegetation providing a variety of nesting, loafing, and feeding sites; shallow feeding areas for wading birds; clear water for foraging by fish-eating birds; and large open lakes for molting and staging areas. The significance of this habitat contribution is maximized by the fact that intensive

row-crop production otherwise dominates the landscape in this part of Illinois.

The important societal values of many wetland functions have been widely documented (Clark and Clark 1979, Greeson et al. 1979, Richardson 1981, Gopal et al. 1982, Adamus 1983, and others). Larson (1976) termed those with highest significance as "red flag" values and suggested that wetlands with such characteristics be given highest priority for preservation. The 4 of 10 "red flag" values proposed by Larson (1976), and adapted by others (Schuldiner et al. 1979, Zorach 1979), documented on this particular study area include (1) having rare, restricted, endemic, or relict flora and fauna, (2) having flora or fauna at, or very near, the limits of their geographic range, (3) being relatively scarce in a given physiographic region, and (4) having high production or use by water, marsh and shore birds. It is notable that of the 24 species recorded, 6 have a status in central Illinois of uncommon, 5 rare, 1 threatened, and 1 endangered (Table 1).

This and other studies (Haynes and Klimstra 1975, Klimstra et al. 1977, Rosso 1979, Konik 1980, Coss 1981, Perkins 1981, Klimstra and Nawrot 1982, and Sponsler 1982) demonstrate that water areas created by surface mining in the Midwest are not a liability, but rather a valuable asset. Unfortunately, current reclamation laws severely limit water development as an alternative use of surface mined lands. Because most of man's efforts to exploit natural resources have negative impacts, the opportunity to create new diverse habitats by employing appropriate reclamation techniques should be encouraged.

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Table 1. Wetland birds observed on surface mines in west-central Illinois; 1979-1980, 1982-1984.

SPECIES	STATUS IN CENTRAL ILLINOIS[a]	# NESTS OBSERVED	# BROODS OBSERVED
CONFIRMED NESTING SPECIES			
Canada Goose	Introduced	242	101
Mallard	Common	17	79
Black Duck	Introduced	0	1
Blue-winged Teal	Uncommon	1	10
Wood Duck	Common	2	4
Hooded Merganser	Rare	0	5
Mute Swan	Introduced	1	0
American Coot	Uncommon	0	2
Common Moorhen	Threatened	0	1
Pied-billed Grebe	Uncommon	0	2
Killdeer	Common	0	several
Spotted Sandpiper	Uncommon	1	1
SUSPECTED NESTING SPECIES			
Lesser Scaup	Rare	—	—
Pintail	Introduced	—	—
American Bittern	Endangered	—	—
Green-backed Heron	Common	—	—
OTHER SUMMER VISITORS			
Green-winged Teal	Rare	—	—
Redhead	Rare	—	—
Common Merganser	Rare	—	—
Great Blue Heron	Locally Common	—	—
Great Egret	Locally Common	—	—
Cattle Egret	Uncommon	—	—
Sora	Occasional	—	—
King Rail	Uncommon	—	—

[a]Status is taken from Bohlen (1978) except those listed as "Introduced".

Fig. 1. Study area in west-central Illinois.

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UNDERWATER SWIMMING OF MALE RATS: AN EFFECTIVE MODEL FOR INVESTIGATING THE PHYSIOLOGY OF ANAEROBIC EXERCISE

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ABSTRACT

The effect of underwater swimming intensity on plasma concentrations of lactic acid and glucose, as indexes of anaerobic glycolysis activity in exercising muscles, was studied in 48 adult male rats divided equally into the non-swimming, 1, 10, 17, 24 and >24 repetitions of underwater swimming groups. At the conclusion of the group number of underwater swimming repetitions, blood samples were collected by decapitation, and then centrifuged for analysis of the plasma by standard procedures. The mean lactic acid levels for the 1 ($\bar{x} \pm$ SE: 13.7 ± 2.3 mEq/1), 10 (23.1 ± 0.7 mEq/1), 17 (20.6 ± 0.9 mEq/1), 24 (17.2 ± 1.3 mEq/1) and >24 (6.9 ± 1.1 mEq/1) repetitions of underwater swimming groups were significantly ($P<0.05$) elevated above the levels for the non-swimming (0.3 ± 0.1 mEq/1) group. The mean glucose levels for the 10 ($\bar{x} \pm$ SE: 195 ± 10 mg%), 17 (226 ± 8 mg%), 24 (243 ± 8 mg%) and >24 (182 ± 22 mg%) repetitions of underwater swimming groups were significantly ($P<0.05$) greater than the values for the non-swimming (120 ± 5 mg%) group. These data indicate that underwater swimming activates anaerobic glycolysis. Furthermore, the intensity of underwater swimming determines the activity of anaerobic glycolysis in working muscles.

INTRODUCTION

Investigators have demonstrated that anaerobic glycolysis is a significant source of muscular energy in intact animals or humans (Dawson et al., 1971; Holmer, 1979; Pendergast et al., 1980), and isolated muscle preparations (Jones, 1973; Piiper et al., 1968) performing intense exercise. Furthermore, studies have shown that the

level of glycolytic activity in exercising muscles is associated with increments in plasma concentrations of lactic acid (Gollnick and Hermansen, 1973; Hermansen and Stensvald, 1972; Komi et al., 1977; Margaria et al., 1963) and glucose (Hagenfeldt et al., 1980; Wahren and Bjorkman, 1981).

The underwater swimming (UWS) of rats has been described as a high intensity training procedure (Halvorsen II et al., 1978); however, the UWS of rats as a model for investigating the physiology of anaerobic exercise remains unclear. Therefore, the present study focused on the effect of increasing the level of UWS intensity on the activity of anaerobic glycolysis by determining the plasma levels of lactic acid and glucose.

MATERIALS AND METHODS

Forty-eight adult male Harlan Sprague Dawley rats, weighing 175-199 g, were maintained in an animal facility with a controlled environment, and supplied with food and water ad libitum. The animals were divided equally into the non-swimming (NS), 1, 10, 17, 24 and >24 repetitions of UWS groups. The animals swam 20 sec according to a procedure that was described in a previous study (Garcy, 1982), and rested 2 min until the group number of UWS repetitions were completed. For the >24 repetitions of UWS group, the maximum number of swimming repetitions were determined by repeating the swimming and resting cycles until the animals were unable to swim on the surface of the water. At the conclusion of swimming the designated or maximum numbers of repetitions, blood samples were collected by decapitation within 1 min following the final repetition of UWS. Samples were centrifuged for analysis of the plasma. Lactic acid concentrations were determined by measuring the oxidation of lactate to pyruvate with a Du Pont Automatic Clinical Analyzer. Glucose levels were obtained by quantifying the rate of glucose oxidation with a Beckman Glucose Analyzer-System I.

The data were evaluated by one way analysis of variance. The statistical significance of differences in means ($P<0.05$) was determined by the Student's-Newman-Kuels test.

RESULTS

The mean plasma concentrations of lactic acid and glucose in each group are presented in Figs. 1 and 2. The data in Fig. 1 indicate that plasma levels of lactic acid tend to increase with number of UWS repetitions up to 10 repetitions, and then decrease, but even at >24 repetitions of UWS remain higher than in the NS group. The lactic acid levels for the 1 ($\bar{x} \pm$ SE: 13.7 ± 2.3 mEq/1), 10 (23.1 ± 0.7 mEq/1), 17 (20.6 ± 0.9 mEq/1), 24 (17.2 ± 1.3 mEq/1) and >24 (6.9 ± 1.1 mEq/1) repetitions of UWS groups were significantly ($P<0.05$) higher than the levels for the NS (0.3 ± 0.1 mEq/1) group. Furthermore, plasma lactic acid levels for groups 1, 10, 17 and 24 repetitions of UWS were significantly ($P<0.05$) more elevated than the values for the >24 repetitions of UWS group. The results also show that lactic acid levels for the 10 and 17 repetitions of UWS groups were significantly ($P<0.05$) greater than the levels for the 1 and >24 repetitions of UWS groups.

The mean plasma glucose concentrations as shown in Fig. 2 are approximately the same in the NS and 1 bout of UWS groups, increase up to 24 repetitions of UWS, and then decrease with >24 repetitions, but are still higher with >24 repetitions of UWS than in the NS and 1 bout of UWS groups. The glucose levels for the 10

($\bar{x} \pm$ SE: 195 ± 10 mg%), 17 (226 ± 8 mg%), 24 (243 ± 8 mg%) and >24 (182 ± 22 mg%) repetitions of UWS groups were significantly ($P<0.05$) elevated above the values for the NS (120 ± 5 mg%) and 1 (100 ± 11 mg%) bout of UWS groups. Moreover, glucose concentrations for the 24 repetitions of UWS group were significantly ($P<0.05$) greater than the glucose levels for the 10 and >24 repetitions of UWS groups.

DISCUSSION

The lactacidemias reported in this study are in accordance with those values published elsewhere for animals and humans performing other forms of exercise in vigorous fashion, such as bicycling (Wahren et al., 1971), running (Holmer et al., 1974) or swimming on the surface of the water (Holmer et al., 1974; Pendergast et al., 1980). Moreover, the elevated levels of plasma lactic acid from a single 20 sec bout of UWS, suggest activation of anaerobic glycolysis which occurs at approximately 60-80% of maximum oxygen uptake (Hermansen and Stensvald, 1972; Jones and Ehrsom, 1982), and within 10 sec from the onset of exercise (Gollnick and Hermansen, 1973). Although, oxygen tensions were not monitored for arterial or venous blood, hypoxia does not appear to be a likely explanation for stimulation of anaerobic glycolysis during UWS, since investigators (Holmer et al., 1974) have shown that there is sufficient oxygen available in order to maintain oxidative metabolism during the performance of intense exercise. Thus, the lactacidemias noted in this study reflect glycolytic responses to exercise loads imposed on the muscles by varying the level of UWS intensity.

The increments in plasma lactic acid with advancing levels of UWS intensities reported herein, have been noted in other studies (Hermansen and Stensvald, 1972; Margaria et al., 1963; Pendergast et al., 1980), and explained on the basis of increased glycolytic activity. Furthermore, the highest elevations in lactic acid which were recorded for the 10 and 17 repetitions of UWS groups, suggest that these levels of exercise intensities stimulated maximal glycolytic activity in the working muscles. On the other hand, the less than maximal concentrations of lactic acid that were associated with animals performing the greatest numbers (>24) of UWS repetitions (Fig. 1) may be attributed to the interaction between the production and the oxidative utilization of lactic acid (Brooks et al., 1973). Hermansen and Stensvald (1972) have shown that the rate of lactic acid removal is accelerated by increasing the intensity of exercise load, whereas other investigators (Jones and Ehrsom, 1982; Robin and Hance, 1980) have cited the acidosis from increased glycolytic rate as having a negative feedback effect on the production of lactic acid.

The levels of glucose during exercise probably are determined by the co-ordinated regulation of muscle glycolysis and hepatic glucose output which are stimulated by catecholamines acting on the α-receptors of these tissues (Clark et al., 1983). The basal levels of plasma glucose observed during the performance of 1 UWS bout (Fig. 2), suggest that the intermuscular stores of glucose were sufficient for maintaining anaerobic glycolysis or production and utilization of glucose were at a steady state during the short duration of exercise. The variable increments in plasma concentrations of glucose for increasing intensities of UWS (Fig. 2), indicate a compromise between glucose production by the liver and utilization by muscles working at various levels of exercise performance (Hagenfeldt et al., 1980).

In conclusion, the results from this study indicate that UWS is an effective stimulus for activation of anaerobic glycolysis. In addition, predictable changes in glycolytic activity may be determined by varying the level of UWS intensity.

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LACTIC ACID

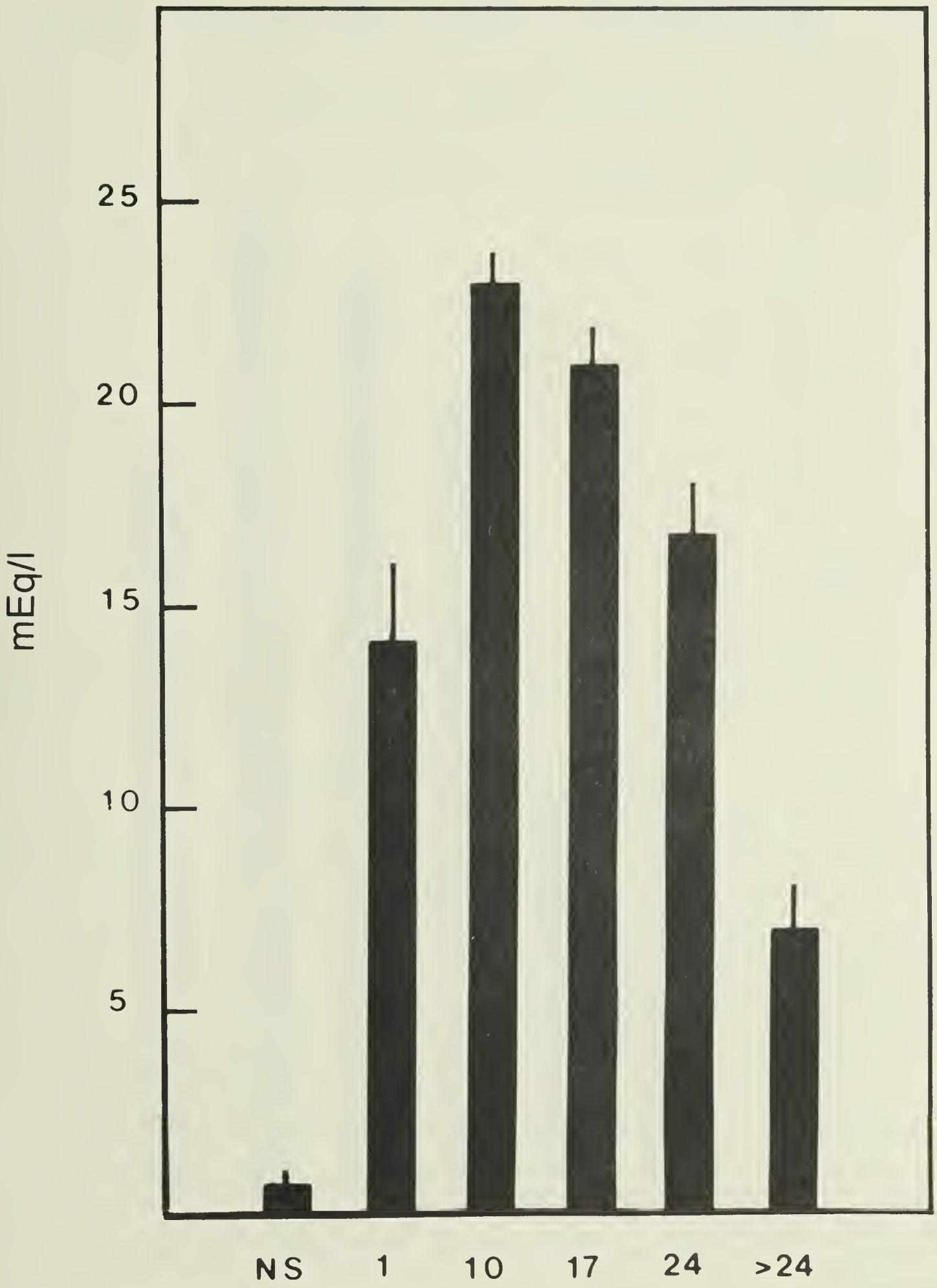

Fig. 1. Plasma lactic acid concentrations (mEq/1) for the non-swimming (NS), 1, 10, 17, 24 and >24 repetitions of underwater swimming groups. Bars with vertical lines indicate the means ± standard errors.

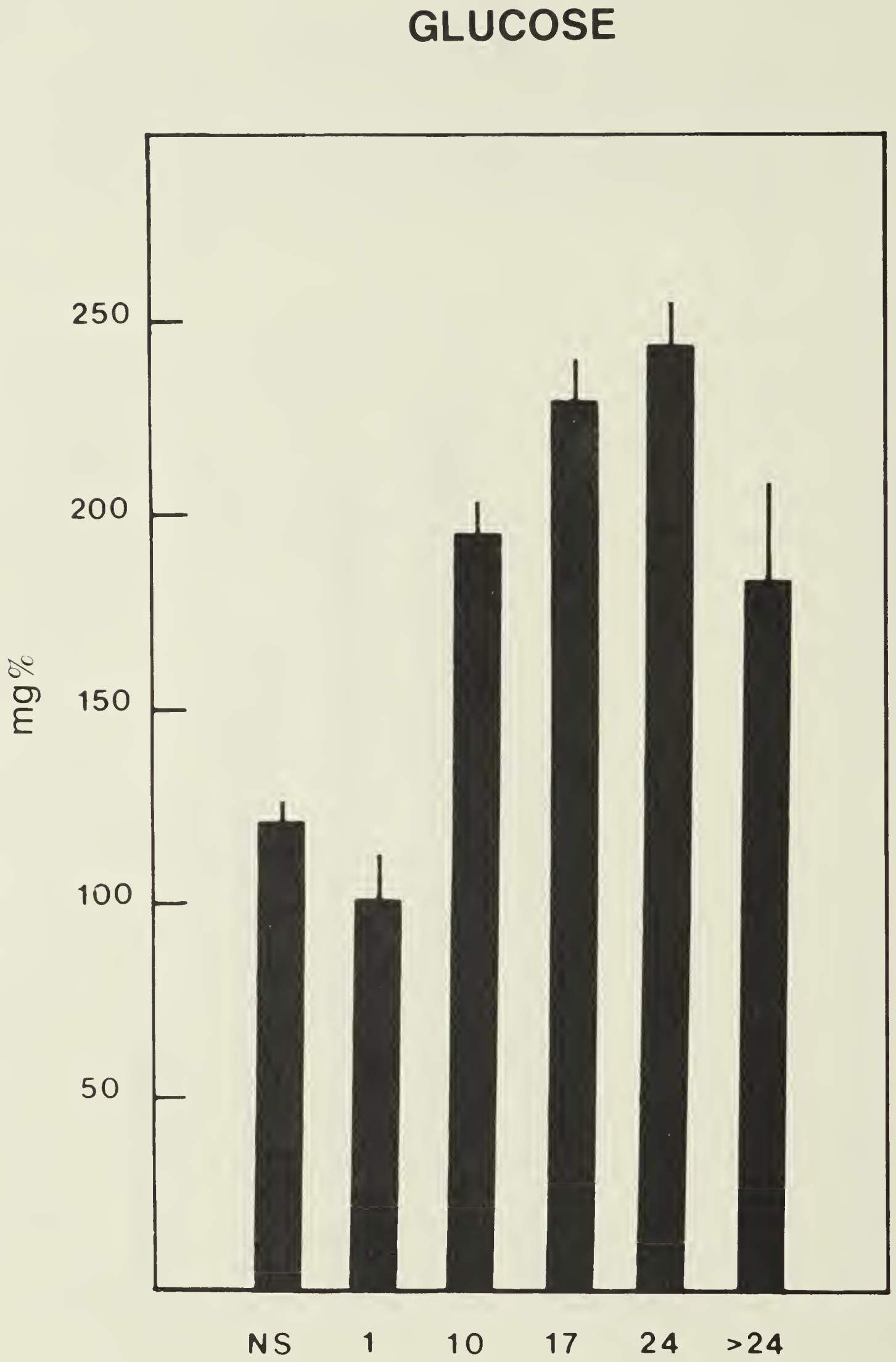

Fig. 2. Plasma glucose concentrations (mg%) for the non-swimming (NS), 1, 10, 17, 24 and >24 repetitions of underwater swimming groups. Bars with vertical lines indicate the means ± standard errors.

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A BRAZILIAN FREE-TAILED BAT (*Tadarida brasiliensis*) IN SOUTHERN ILLINOIS

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ABSTRACT

The second record of a Brazilian free-tailed bat from Illinois is reported. A young female was collected 18 October 1984 from Carbondale, Jackson County.

RESULTS AND DISCUSSION

A female free-tailed bat (*Tadarida brasiliensis* Rafinesque) was collected 18 October 1984 by Mr. Jeff Christopherson on the campus of Southern Illinois University, Carbondale, Jackson County (SIU-C Zoology No. 1521). Body measurements were: total length, 94 mm; tail length, 31 mm; hind foot length, 10 mm; ear length, 16 mm; and forearm length, 42 mm. Skull measurements were: total length, 16.5 mm; zygomatic breadth, 9.2 mm; interorbital breadth; 4.2 mm; breadth of braincase, 8.5 mm; breadth of rostrum at M^2, 6.9 mm; length of maxillary toothrows, 6.1 mm; and length of mandibles, 11.6 mm. The specimen was in excellent condition, and was considered a juvenile based on the lack of tooth wear.

The only previous record of *T. brasiliensis* in Illinois is a specimen from the campus of Northern Illinois University, DeKalb, DeKalb County, taken on 17 October 1969 (Walley, 1970). On the basis of coloration and measurements, presumably size characteristics given by Shamel (1931), Walley assigned the initial Illinois specimen to the western subspecies *mexicana*, as opposed to the eastern subspecies *cynocephala*. However, as noted by Schwartz (1955), the degree of overlap in skull measurements among these two subspecies is considerable, and probably precludes subspecific designation on that basis.

Both Illinois specimens are probably *T. b. mexicana*, however, as this subspecies is highly migratory, while *cynocephala* is not. Unlike the recent range expansion of *T. brasiliensis* into North Carolina (Lee and Marsh, 1978), both Illinois speci-

mens probably represent only extralimital occurrences by migrants. There are two extralimital records for Ohio (Smith and Goodpaster, 1960; Mills, 1971), however, *T. brasiliensis* has never been reported from a state bordering Illinois. Most extralimital records of this species occur in fall, during migration periods.

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DIFFERENTIAL EFFECTS OF LIGHT UPON FECUNDITY IN *TRIBOLIUM CASTANEUM*

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ABSTRACT

The effect of light upon fecundity of two genetic strains (black and wild type) of *Tribolium castaneum* was investigated by using continuous darkness, continuous light and an alternate light/dark treatment. Both strains laid significantly fewer eggs in continuous light than in continuous darkness or light/dark; egg numbers recovered in the latter two conditions were similar. A significant interaction was observed between genotype and light treatment and was attributed to many fewer eggs being laid by wild-type females than by black females when exposed to continuous light. Reduction in egg numbers laid was attributed in part to a reduction of normal activity of mating as directly influenced by the sudden introduction of light without prior acclimation.

INTRODUCTION

Relatively little is known concerning the influence of light upon the fecundity of flour beetles of the genus *Tribolium*. In a study designed primarily to examine suitability of oviposition site, Stanley and Grundmann (1965) reported that for the confused flour beetle, *Tribolium confusum* Jacquelin duVal, significantly greater egg numbers were laid in darkness than in normal room illumination. Hawk *et al.* (1974) reported that egg laying rate for the red flour beetle, *Tribolium castaneum* (Herbst), was lower when mated adults were exposed to light under different temperature levels than when they were exposed to complete darkness.

The purpose of the present study was to explore further the effects of light on fecundity in *T. castaneum*, and to check the uniformity of response in different genetic strains under differing light regimes.

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MATERIALS AND METHODS

The two populations of *T. castaneum* used in this study were derivatives of broad-based, randomly mating, heterogeneous base populations differing only by a single genetic marker, black body color (*b*). The populations, derived originally from the Purdue + and *b* Foundation Stocks, have been maintained in our laboratory since 1963.

All beetles were reared in complete darkness in a Sherer-Gillett walk-in environmental chamber operating at 32 ± 1°C and 70 ± 2% r.h. on a standard medium of whole wheat flour and dried brewer's yeast (95:5 ratio by volume). Each stock culture was contained in a rectangular plastic box (17.8 × 12.7 × 6.2 cm) containing 200 g medium and experimental observations were made on single pair matings in 20 ml glass coffee creamers containing 5 g of triple sifted standard medium to facilitate recovery of eggs.

The study was conducted in 8 replications over an 8-month period, each replication, with the exception of Replications 6 and 8, consisting of 15 single pair matings per light treatment. Replications 6 and 8 had only 10 single pair matings due to an unexplained increase in mortality prior to initiation of the treatment period. To initiate each replication, approximately 200 pupae were collected and sexed from each population which, under our normal laboratory conditions, were reared in complete darkness. The pupae were kept in single-sexed groups until eclosion and then the required number of adults were mated, have been randomly selected from these surviving. All paired beetles were kept in complete darkness for 15 days, and were then transferred to fresh creamers with "egg medium" and placed in their respective light treatments for 24 h.

The experimental photic conditions to be compared were: (1) continuous light for a 24-h egg-laying period, (2) continuous darkness for a 24-h egg-laying period, and (3) an egg-laying period in 12 h of light followed by 12 h of darkness (hereafter referred to as the light/dark treatment). The light/dark treatment was coordinated with a fixed day-night cycle; i.e., 0800 hours to 2000 hours (8:00 a.m. to 8:00 p.m.). The light source was provided by five overhead flourescent lamps (Silvania 40W, Cool White-HO) in the environmental chamber, approximately 1.8 m from the culture containers.

All eggs laid by each female during the 24 h period were recovered and counted. Fecundity of the beetles was measured following the procedure outlined by Park and Davis (1945), using a linear egg counting stage (Muir and Grossman, 1973) for the counting process. Hatchability (number of eggs hatching expressed as a percentage of the number of eggs laid) was measured only during Replication 5. This was measured as follows: eggs were counted, returned to the flour, and all larvae hatching from the eggs were counted 96 h later.

RESULTS AND DISCUSSION

Fecundity of the two genetic strains differed; black (*b*/*b*) consistently laid more eggs under each of the three light treatments (Table 1). Egg production for both strains under continuous light was significantly lower than that under either continuous darkness or light/dark. The fecundity values recorded for these latter two treatments were not greatly different.

The analysis of variance (Table 2) revealed that there was also significant interaction (G × T) between genotype and light treatment. The major contributor to this interaction was the degree of response by each genotype to each light treatment. Decreased egg production for the wild-type strain in continuous light compared to that in complete darkness was proportionately greater than the decrease noted for the black strain under the same treatments. Though nonsignificant, differences in fecundity observed between the continuous darkness and the light/dark treatments behaved in a similar fashion. Clearly the reduction of egg numbers due to continuous light exposure is an indication that a suboptimal environment was created for both strains, however, their reaction to the suboptimal environment was different. Similar genotype by light interactions were not observed by Hawk *et al.* (1974); thus, further exploration of the implications of this interaction is desirable, particularly as it may affect overall fitness of the strains involved.

One additional measure of fitness can be provided by hatchability. There was no obvious effect of light *per se* upon egg hatchability, although the overall hatchability of wild type was considerably higher than that observed for black (Table 3). Neither did there appear to be any significant interaction for this variable.

The fecundities measured are net values, and the analysis of fecundity is for beetles of restricted age and known history under favorable constant physical conditions except for light. *Tribolium* adults are normally photonegative (Park, 1934), tending to cluster in shaded portions of their culturing container and then crawling into the medium when exposed to direct light for a period of time. Observations showed that the experimental beetles in this study reacted in the same manner during the treatment periods.

Park (1934) reported that most copulation occurs on the surface of the medium with prolonged tunnelling to escape light tending to reduce the frequency of copulation. Thus, when mating activity is reduced, the number of eggs laid is likely to be reduced since an absence of the stimulation of recopulation would be coupled with a direct discouragement of egg laying due to exposure of light.

The lower rate of fecundity observed under continuous light can further be explained by the lack of acclimation of the adults to light exposure. Cloudsley-Thompson (1953a,b) reported that the strong photonegative response exhibited by *Tenebrio molitor* L. was ameliorated after prolonged exposure to light, with near normal activity of adults on the surface being observed.

Similarly, Arbogast and Flaherty (1973) showed that light response for both *T. castaneum* and *T. confusum* is positively correlated with the state of reproductive development of the beetle. Their study showed that young adults were extremely inactive when exposed to light but the intense photonegative response decreased as reproductive maturity increased, with stabilization of the intensity of light response being achieved by the sixteenth day . This latter was attributed to a speculation that mating activity tended to decrease the photonegative response exhibited in *T. castaneum*, particularly since their experimental animals were reared in alternating light-dark conditions before testing. Thus, beetles reared under constant darkness before being exposed to continuous light, as in the present study, would be expected to take some time to get accustomed to the light before resuming normal copulation. Reduction in copulation would then be expected to effect a reduction in the number of eggs being laid, and any difference in fecundity would be due to the immediate effect of light.

Hawk *et al.* (1974) also have reported reduction of fecundity in *T. castaneum* when exposed to continuous light. However, by the end of the third successive egg laying period, they noted that the photonegative response was less obvious, and that the difference between fecundity levels of their two treatment groups was less striking, probably due to acclimation.

The failure to observe larger differences than those realized in fecundity for the continuous darkness and light/dark treatments is of concern. Initial exposure to light may well have disrupted the normal surface activities of the beetles, but they compensated for the disruption very rapidly when once again introduced to darkness. Whether exposure to light affects not only mating activity, but also oviposition activity remains to be seen, although our data suggest that this may be the case.

While light apparently affects fecundity through reducing mating activity, there is no evidence from our study that fertility (measured by hatchability percentages) similarly suffers. Hawk *et al.* (1974) also have reported that light exposure does not adversely affect hatchability percentages.

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Table 1. Fecundity values[a] (Mean ± standard error) for two genetic strains of *Tribolium castaneum* under three light treatments.

Genotype	Number of females	Light treatment: Continuous darkness	Light treatment: 12 h:12 h light/dark	Light treatment: Continuous light
b/b	110	24.6 ± 0.12	23.6 ± 0.15	18.9 ± 0.12
+ / +	110	17.8 ± 0.09	17.1 ± 0.20	13.5 ± 0.07

[a]Number of eggs/female/24-h egg laying period.

Table 2. Analysis of variance for fecundity of two genetic strains of *Tribolium castaneum* under three light treatments.

Source of variation	d.f.	Mean square
Genotype (G)	1	6517.38**
Treatment (T)	2	1620.74**
G × T	2	30.63**
Error (corrected)[a]	654	0.45

**P < 0.001.
[a]harmonic mean.

Table 3. Hatchability[a] for two genetic strains of *Tribolium castaneum* under three light treatments.

Genotype	Light treatment: Continuous darkness	Light treatment: 12 h:12 h light/dark	Light treatment: Continuous light
b/b	87.3 ± 0.75	88.8 ± 0.89	86.4 ± 0.70
+ / +	96.3 ± 1.57	96.4 ± 1.57	97.7 ± 1.20

[a]Expressed as percent eggs hatching.

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RANGE EXTENSION OF THE BADGER *(TAXIDEA TAXUS)* IN SOUTHERN ILLINOIS

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ABSTRACT

The range extension of the badger (*Taxidea taxus*) into southern Illinois is reported.

INTRODUCTION

The badger is considered a resident of open grasslands, prairies, and treeless regions (Hoffmeister and Mohr 1972, Lindsey 1982). The badger's southern range boundary in Illinois as of the late 1940's (Hoffmeister and Mohr 1972) was Fulton and Douglas counties. These central Illinois counties are within ecotypes compatible with stated badger habitat. Klimstra and Roseberry (1969) reported 1965 occurrences in Randolph and Washington counties; these represented 150 km southward extension of badger range. Both counties are well within the southern one-third of the state and outside the major prairie region of Illinois. This paper documents further southward expansion of this mammal's range in Illinois.

SPECIES ACCOUNT

On 25 June 1984 a road-kill badger picked up on Route 13 (Sec. 12, T9S, R2W) between Murphysboro and Carbondale, Jackson County (1, Fig. 1), was submitted to the Cooperative Wildlife Research Laboratory. The carcass, in poor condition with most of the visceral and skeletal features crushed, was a female weighing 6.95 kg and judged to be an adult. Examination of the reproductive tract and mammary tissue revealed no evidence of breeding this year. Another badger was killed on Route 13 approximately 0.6 km east of Murphysboro on 31 August 1978 (G. Hubert per. comm.); this specimen is believed deposited at the University of Illinois. These two

reports represent the southern most current known occurrence of the badger in Illinois.

According to M. Sweet (in litt.) other recent records of the badger in the southern Illinois area are: (2) Clinton Co.: 8 km west of Carlyle on Route 50, road-kill, 19 February 1983. (3) Franklin Co.: 3.2 km north of Benton, road-kill, 26 June 1982. (4) Jefferson Co.: Sec. 19, T15S, R4E, trap-mortality, 3 January 1982. 0.8 km east, southeast of Walnut Hill, road-kill, 12 April 1983. (5) Perry Co.: Sec 17, T5S, R1W, trapped and released 5 January 1983. (6) Randolph Co.: 6.5 km west of Prairie du Rocher. (7) Washington Co.: Sec. 12, T3S, R5W, sighting, August 1983. Sec. 29, T3S, R4W, sighting, Summer 1979 (Fig. 1).

DISCUSSION

Although these records indicate the badger has recently established a population in southern Illinois, this may constitute reinvasion of a previously occupied area. Robert Kennicott (Cory 1912) stated that as late as 1928 badgers occurred as far south as the Kaskaskia River. Though this report is not very specific, it is of interest that Clinton, Randolph, and Washington counties lie within the Kaskaskia River drainage.

At the time of Kennicott's observation the land of southern Illinois consisted primarily of poorly drained upland soils underlain by a hard fragipan and frequently flooded bottom lands (Schwegman 1973). Possibly two major land-use practices in southern Illinois may contribute to improvements in the quality of badger habitat. A substantial increase in row crop acreages has resulted from improved drainage and intrusion into previously forested lands. Jones et al. (1983) declared badgers to be denizens of both grasslands and forest edge. Extensive coal surface-mining has disrupted the fragipan, created relief in an otherwise flat topography, and produced large expanses of both temporary and permanent grassy areas. Both practices result in soils more suitable for burrows and habitat capable of supporting large numbers of rodents. According to Mumford and Whitaker (1982) there has been similar southward spread of the badger and other prairie species in Indiana. They report badger habitat that includes disturbed lands such as railroad rights-of-way, hay fields, and abandoned gravel pits. Possibly man's activities have created more favorable habitat in southern Illinois and facilitated establishment of badgers in recent years.

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L. Nelson, Jackson Co. Animal Control Warden, submitted a road-kill badger for necropsy. G. Hubert, Fur Bearer Biologist Illinois Department of Conservation, and M. Sweet, Endangered Species Coordinator Illinois Department of Conservation, cooperated in providing species accounts. Drs. A. Woolf and W.D. Klimstra provided helpful criticisms of the manuscript.

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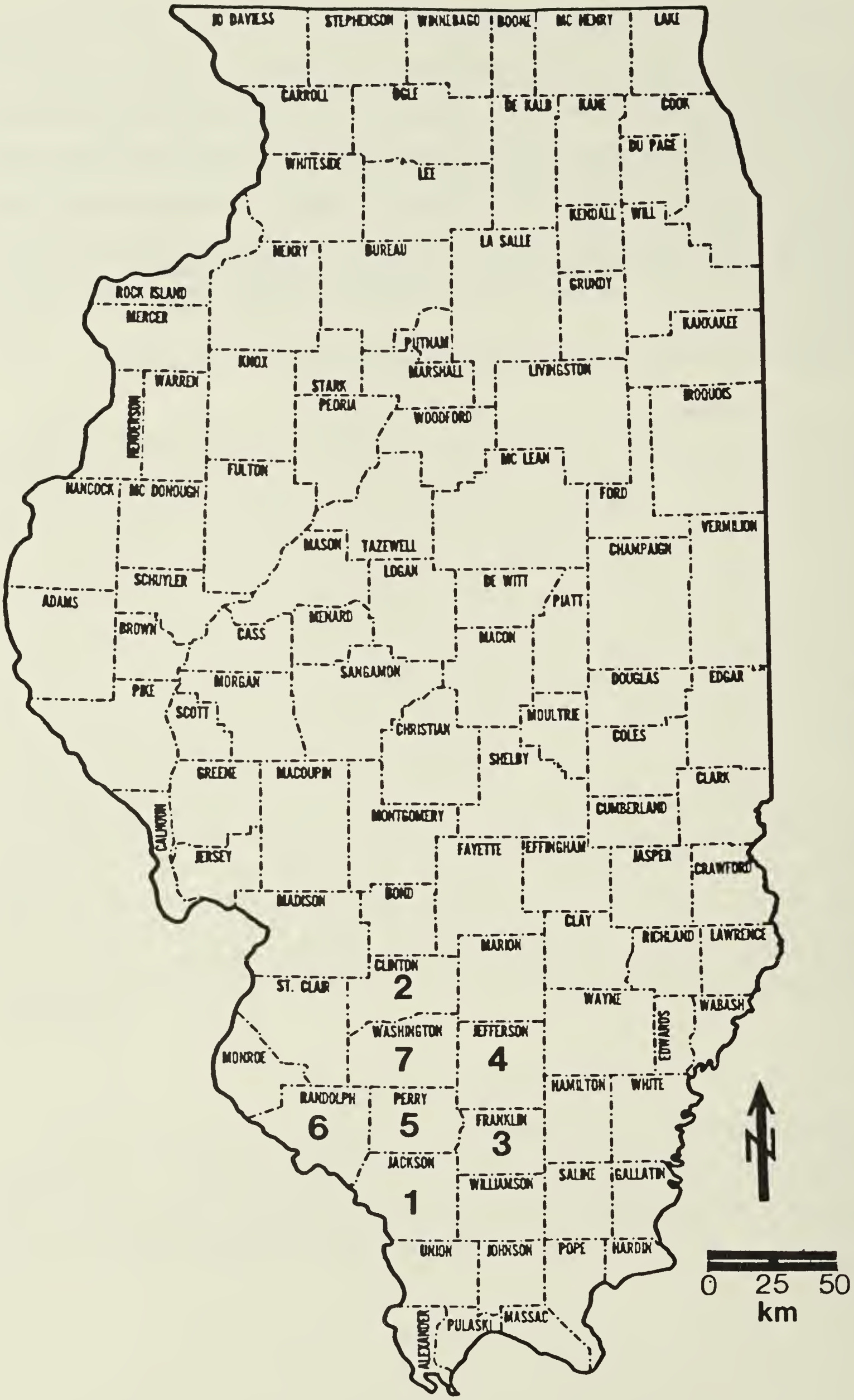

Fig. 1. Documented occurrences of badgers in southern Illinois 1979-1984.

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DAILY GROWTH INCREMENTS IN OTOLITHS OF LARVAL WALLEYE *(STIZOSTEDION VITREUM)*

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ABSTRACT

Growth increments were formed daily in the otoliths of laboratory-reared walleye (*Stizostedion vitreum*) larvae for at least 19 days after swimup. The periodicity of increment formation did not differ between two groups of walleye growing at different rates. A metamorphic check in the otolith corresponding to the date of swimup (first feeding) was counted as the first daily increment. Distinct increments formed in the otolith prior to swimup but the number of increments did not correspond to the number of days from hatching. Subdaily increments were also visible in all otoliths examined, but were weakly defined. A linear relationship existed between otolith radius and fish length. Increments observed in the otoliths of field-collected walleye larvae were more distinct than those in laboratory-reared specimens, suggesting that age estimates of field-collected specimens may be more accurate.

INTRODUCTION

Daily growth increments in the otoliths of larval and juvenile fish are useful for estimating spawning dates and growth (Struhsaker and Uchiyama 1976; Methot

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and Kramer 1979; Radtke and Dean 1982; Radtke and Scherer 1982). This information can increase substantially our understanding of the effects of environmental factors on larval fish populations and subsequent development of year-class strength.

Daily increments consist of adjacent bands of calcium carbonate and organic matrix which make up the smallest visible growth units of the otolith (Pannella 1971). These increments appear as light and dark bands, respectively, under transmitted light. The formation of daily increments appears to be regulated by an internal circadian rhythm (Campana and Neilson 1982), but also may be influenced by photoperiod (Taubert and Coble 1977), feeding frequency (Neilson and Green 1982), and temperature (Taubert and Coble 1977).

Interspecific variation in the initiation of increment formation (Brothers et al. 1976) and evidence that not all species may deposit increments with daily periodicity (Geffen 1982) make it necessary to validate the frequency of increment formation for individual species. This study attempts to (1) document the occurrence of daily growth increments in the otoliths of laboratory-reared larval walleye, (2) determine the age at which increment formation begins, and (3) describe the relationship between otolith growth and fish growth.

METHODS

The otoliths of two groups of walleye were examined. Group A, obtained as fertilized eggs from Ohio, were incubated at 9-11 C until hatching, then temperature was gradually increased to 15 C over a 2-week interval. Eleven days elapsed between hatching and the start of feeding (swimup) for this group.

Group B walleye, obtained as prolarvae from Minnesota, were acclimated to 16 C, and then the temperature was gradually increased to 25 C over a 2-week interval. Approximately 7 days elapsed from hatching to swimup for Group B.

Both groups of walleye were stocked in circular fiberglass tanks (1.8-m diameter, 1500-L) at 25,000 per tank and fed live brine shrimp, *Artemia* sp., nauplii for 12 days. Thereafter, commercial salmon starter was also offered. Both groups of walleye were held at a constant photoperiod of 12-h light and 12-h dark.

Group A walleye were sampled at 16, 14, and 30 days after hatching. Group B walleye were first sampled 9 days after hatching and then at unequal intervals over the next 14 days. All fish were preserved in 70% alcohol.

Sagittae, the only otoliths used in this study, were dissected from preserved specimens and mounted in thermoplastic cement on glass slides. No further preparation was needed to observe increments. A drop of immersion oil, applied to each otolith, increased resolution and all otoliths were observed at 100-200x.

To prevent bias in increment counts, the otoliths from the two groups were intermixed and randomly assigned identification numbers. Individual otoliths were aged on two separate dates and their average was used as the estimated age of the fish.

To determine the relationship between sagittae radius and fish length, each otolith was measured to the nearest 0.01 mm along a plane extending from its center into the posterior field, following the plane of maximum growth. Measurements along this plane could be made for 45 of the 46 otoliths aged.

RESULTS

Otoliths removed from the first sample of Group A walleyes (n = 5) had 9-11 increments, whereas otoliths from the first sample of Group B walleyes (n = 5) had 6 increments. In both instances, the number of increments exceeded the number of days from swimup (first feeding) but were fewer than the number of days from hatching. Otoliths of both groups contained a dark band or check (approximately 0.03 mm from the center of the otolith) which corresponds to the date of swimup. This apparent metamorphic check, present in all otoliths examined, was designated as the first increment in subsequent counts; thus, increment counts estimated the number of days from swimup.

For both groups of walleye there was a close correspondence between the number of days from swimup and increment counts (Table 1). Correlation coefficients (r) relating number of increments to age were greater than 0.95 for both groups, while slopes and intercepts did not differ significantly between the two regressions (analysis of covariance; $\underline{P}>0.01$). Thus, data from both groups were pooled to produce the predictive regression:

$$(1)\ Y = 1.05(X) - 0.64;\ r = 0.97$$

where Y is age in days from swimup and X is the number of otolith increments.

Differences in regression line slopes relating length to age indicated that Group B walleyes grew faster than Group A walleyes (analysis of covariance; $\underline{P}>0.01$; Table 2), probably because rearing temperatures were higher. Differences in growth, however, did not affect the relationship between increment counts and age; therefore, increment counts were independent of growth rate over the range of growth rates observed. Fish length and otolith radius data from both groups of walleye were pooled and the resulting plot revealed a linear relationship (Figure 1). The assumption of linearity was supported by the significance of the relationship ($F = 449.7$; 1,43 df; $r = 0.96$) which was not improved by a double log transformation ($r = 0.94$). Thus, otolith radius was directly proportional to fish length over the size range examined.

DISCUSSION

The age at which daily increments begin forming differs among species (Brothers et al. 1976), possibly reflecting egg size and length of the incubation period (Radtke and Dean 1982; Radtke 1984). Consequently, the onset of increment formation needs to be determined for each species. Walleye began increment formation from 3 to 7 days after hatching but 4 to 6 days before swimup. Therefore, the metamorphic check that delineated swimup was used as the starting point for increment counts. This metamorphic check, which reflects the transition from endogenous to exogenous feeding (Marshall and Parker 1982; Radtke 1984), supports the hypothesis that otoliths provide an accurate record of the physiological changes that occur during a fish's life.

Prolarval increments (those formed prior to swimup) have been reported for a variety of species (Taubert and Coble 1977; Miller and Storck 1982). They generally are more weakly defined than postlarval increments and may become obscure as the otolith core becomes more opaque with increasing age (Miller and Storck 1982; Davis et al., in press). The 4 to 6 prolarval increments in walleye otoliths, however, were quite distinct and were clearly visible in all otoliths examined. Since

the number of prolarval increments did not correspond to the number of days from hatching to swimup, it is important that they be excluded from increment counts and ages be determined as the number of days from swimup. Subdaily increments were observed in nearly all otoliths from walleye older than 5 days from swimup. They were usually easily distinguished from daily increments because they were weakly defined and not present in the lateral field of the otolith. The occurrence of these subdaily patterns have been noted for a number of species though factors affecting their occurrence are poorly understood. Factors implicated in their production include temperature (Brothers 1978) and feeding frequency (Campana 1983).

Increments similar to the daily increments found in our laboratory-reared specimens have been observed in otoliths from young-of-year walleye from Lake Shelbyville, Illinois. Increments in otoliths from wild-caught specimens exhibited greater contrast than those in otoliths from laboratory-reared specimens and subdaily and prolarval increments were relatively indistinct. Thus, assuming that the increments observed were also deposited daily, otolith ages of wild-caught specimens may be more accurate than those of laboratory-reared specimens.

Because otolith growth was directly proportional to body growth, daily increments can be used to back-calculate lengths and growth rates. Thus, daily increments provide a more precise method for evaluating growth of walleye larvae than has been previously available. The effects of various environmental factors on the otolith radius to fish length relationship, however, are poorly understood and warrant further investigation.

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Table 1. Chronological age and number of growth increments in otoliths of larval walleye.

Number of larvae	Age (post-swimup)	Mean number of increments	SE
	Group A		
5	5	5.8	0.8
5	13	12.6	1.1
8	19	18.4	0.9
	Group B		
5	2	2.8	1.1
3	4	4.3	1.2
5	6	7.2	1.8
3	11	11.0	3.0
3	12	12.0	1.0
4	14	13.8	2.1

Table 2. Regression statistics of total length against age in days from swimup for walleye larvae.

	Number of fish	Intercept	Slope	SD of slope	r
Group A	18	8.28	0.30	0.04	0.90
Group B	28	8.84	0.61	0.03	0.96

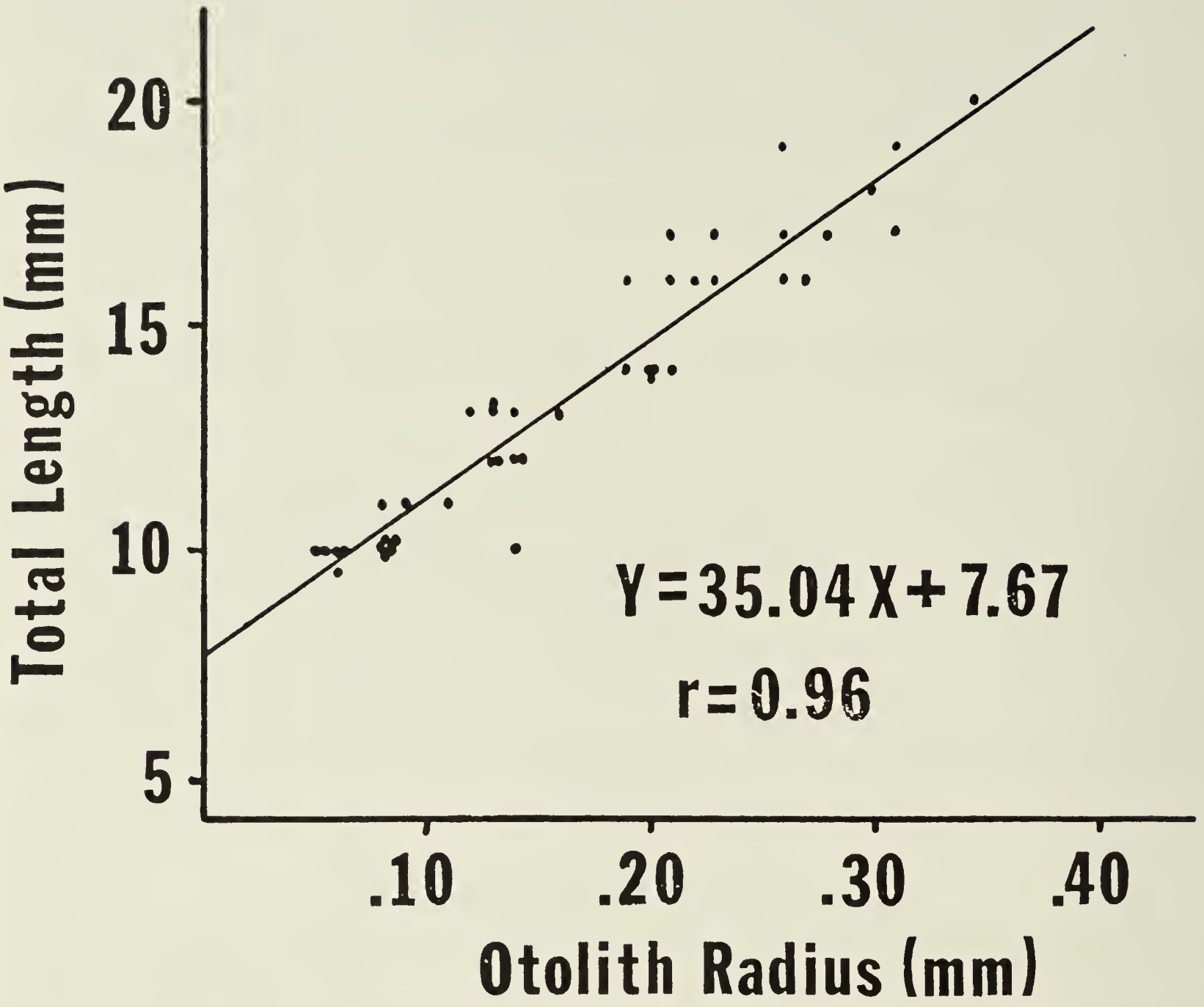

Fig. 1. Relationship of total length (Y) to otolith radius (X) for walleye larvae (n = 45).

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QUANTITATIVE DETERMINATION OF 2-METHYL-3-AMYLPYRROLE, A PRECURSOR OF PRODIGIOSIN††

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ABSTRACT

Prodigiosin, a characteristic red antibiotic pigment produced by *Serratia marcescens*, is synthesized by the enzymatic coupling of two precursors, 2-methyl-3-amylpyrrole (MAP) and 4-methoxy-2,2′-bipyrrole-5-carboxaldehyde (MBC). When MAP is replaced by 2,4-dimethyl-3-ethylpyrrole (DEP), a prodigiosin analog can be synthesized. Although MAP and MBC have been extracted from the corresponding mutants producing a single precursor and analyzed by high-performance liquid chromatography (HPLC), the extraction procedures are tedious and time consuming. In this paper we report a single-step quantitative method of determining the amount of MAP in the culture medium of strain WF. A standard curve was constructed with DEP, extracted MBC from mutant 9-3-3, and condensing enzyme from mutant 9-3-3. The absorbance of the prodigiosin analog formed between DEP and MBC per μg of DEP was calculated. The amount of MAP in the culture medium of mutant WF used in the syntrophic formation of prodigiosin was determined according to the standard curve and expressed as μg of DEP. This method was applied to determine the effect of metal ions on MAP synthesis.

INTRODUCTION

Prodigiosin is a characteristic red pigment antibiotic synthesized by *Serratia marcescens*. The biosynthetic process of prodigiosin in *S. marcescens* is quite complex.

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It is influenced by various factors, such as temperature (Hussain Qadri and Williams, 1972; Morrison, 1966), amount of oxygen (Heinemann et al., 1970), composition of the growth media (Williams and Hussain Qadri, 1979), detergents (Feng et al., 1982), and certain antibiotics (Tsang and Sheung, 1980; Williams and Gott, 1964; Williams and Hassain Qadri, 1979). A bifurcated pathway was proposed for prodigiosin formation (Franklin and Snow, 1975; Morrison, 1966). Two precursors, a monopyrrole, 2-mythyl-3-amylpyrrole (MAP) and a bipyrrole, 4-methoxy-2,2′-bipyrrole-5-carboxaldehyde (MBC) are synthesized separately, then enzymatically condensed to form the pigment (Williams and Hussain Qadri, 1979). It was shown by high-performance liquid chromatography (HPLC) that the reduction in pigment synthesis in the presence of polymyxin B, a membrane active antibiotic, was partly due to a reduction in MAP synthesis (Tsang and Feng, 1983). It was the first time that the effect on pigment synthesis at the level of precursor synthesis was reported. However, the extraction procedures were tedious and time consuming. Therefore, the objective of this study was to find an alternative method to HPLC to quantitate MAP in *S. marcescens*.

Syntrophic pigment synthesis serves as the basis of MAP quantitation in the culture medium of strain WF, a mutant producing MAP but not MBC. Syntrophic pigment synthesis involves the cross-feeding of precursors for pigment formation when either one or both of the precursors are supplied to the cells containing the condensing enzyme. When 2,4-dimethyl-3-ethylpyrrole (DEP) was replaced by MAP, a syntrophic pigment analog was formed. Since DEP can be purchased, it was a logical choice to use DEP to construct a standard curve.

It has been reported that Zn(II) was the most inhibitory first transition metal ion on pigment formation in the wild-type strain 08 (Furman et al., 1984). Therefore, this method was applied in the study of the effect of Zn(II) on MAP synthesis in *S. marcescens* strain WF.

MATERIALS AND METHODS

Chemicals

$Zn(OAc)_2.2H_2O$ was used in this study (Fisher CP. Pittsburg, Pennsylvania, U.S.A.). 2,4-dimethyl-3-ethylpyrrole (DEP) was obtained from Aldrich Chemical Company, Milwaukee, Wisconsin, U.S.A. MBC was extracted from the growth medium of mutant 9-3-3 according to the method previously described (Feng et al., 1982).

Bacterial Strains and Growth Conditions

S. marcescens mutant WF and mutant 9-3-3 were used in this study. These non-pigmented mutants were kindly supplied by Professor R.P. Williams, Baylor College of Medicine, Houston, Texas. Mutant WF can only synthesize MAP while mutant 9-3-3 can only synthesize MBC (Silverman and Munoz, 1973).

Bactopeptone (0.5%)-Glycerol (1%) Broth (PGB) (Difco, Detroit, Michigan) was used for bacterial cultivation. PGB was found to be an excellent medium for the synthesis of prodigiosin and its precursors (Williams and Hussain Qadri, 1979). Bacterial cells were grown in a 125 ml Erlenmeyer flask containing 30 ml of broth in the presence or absence of Zn(II) in a shaker bath at 100 rpm at 25°C. The concentration of Zn(II) used was 15.63 μg/ml, the maximum concentration which allows growth to occur in its presence (Furman et al., 1984). After 24 hr growth, the bac-

terial culture was centrifuged at 10,000 rpm in a Sorvall SS-3 centrifuge to separate the cells from the growth media.

Syntrophic Pigment Synthesis

After 9-3-3 and WF cultures were centrifuged, the supernatants were shown to contain MBC and MAP, respectively. Both the WF and 9-3-3 mutants, and the wild-type strain 08, produce the enzyme required for condensation to occur in the terminal step of prodigiosin synthesis. Mutant 9-3-3 cells were chosen for the source of the enzyme since they do not produce MAP, the compound to be measured.

Syntrophic pigment synthesis was used to estimate the amount of MAP in WF cultures before its extraction for HPLC analysis (Feng et al., 1982). When isolated MBC and condensing enzyme from 9-3-3 cells were supplied in excess to aliquots of WF supernatant containing MAP, prodigiosin was formed. The standard curve was constructed with different amounts of DEP along with excess MBC and condensing enzyme to form a syntrophic pigment analog.

Extraction and Spectrophotometric Measurements

The prodigiosin and prodigiosin analog produced were extracted with a 1% acetic acid/methanol solution. The amounts of these pigments synthesized were determined spectrophotometrically at 534 nm (Williams et al., 1956) with a Beckman Model 35 spectrophotometer. The absorbance of prodigiosin produced was used as an indirect measurement of MAP content in the sample.

Cellular Protein Content Determination

The cellular protein contents of the cultures were determined by the method of Lowry et al. (1951) after the cells were hydrolyzed overnight with NaOH.

RESULTS AND DISCUSSION

Figure 1 shows the DEP standard curve which is linear in the range of 1 to 4 μg of DEP. The slope factor for the standard curve was expressed as absorbance units/μg DEP. Figure 2 represents the amount of pigment produced when MAP was provided by the WF culture. The addition of supernatant containing MAP to excess MBC and condensing enzyme produced the syntrophic pigment which was extracted and monitored at 534 nm. A linear relationship between various amounts of supernatant and the absorbance of the pigment formed was established. In this experiment the slope of this line was shown to be 0.772 absorbance units/ml supernatant. From the standard curve, it was possible to convert the amount of MAP in terms of DEP. The same approach was used when the culture was grown in the presence of 15.63 μg/ml Zn(II) (Figure 3). In this case the slope of the line was shown to be 0.266 absorbance units/ml supernatant. In comparison with the slope factor in the absence of Zn(II), a decrease in the slope indicated a reduction in MAP synthesis. In order to monitor the growth of the organism under these conditions, a measurement of the cellular protein content was determined. When the protein content was compared in the presence and absence of Zn(II), there was an average reduction of approximately 16% in cultures containing Zn(II). From the slope factors of the curves (Figures 2 and 3), it could be shown that the synthesis of MAP was reduced by almost 70% by the presence of Zn(II) in the growth medium. When the protein content was taken into account, there was approximately a 64% reduction in MAP expressed

as μg DEP/mg protein. This decrease was due to a reduction in protein synthesis in cultures containing Zn(II).

These results indicate that this method can be used successfully in quantitating the amount of MAP in WF cultures. It is a rapid method in comparison with that employing the use of HPLC. We plan to use this method to study the effect of other transition metal ions on the synthesis of prodigiosin and its precursors.

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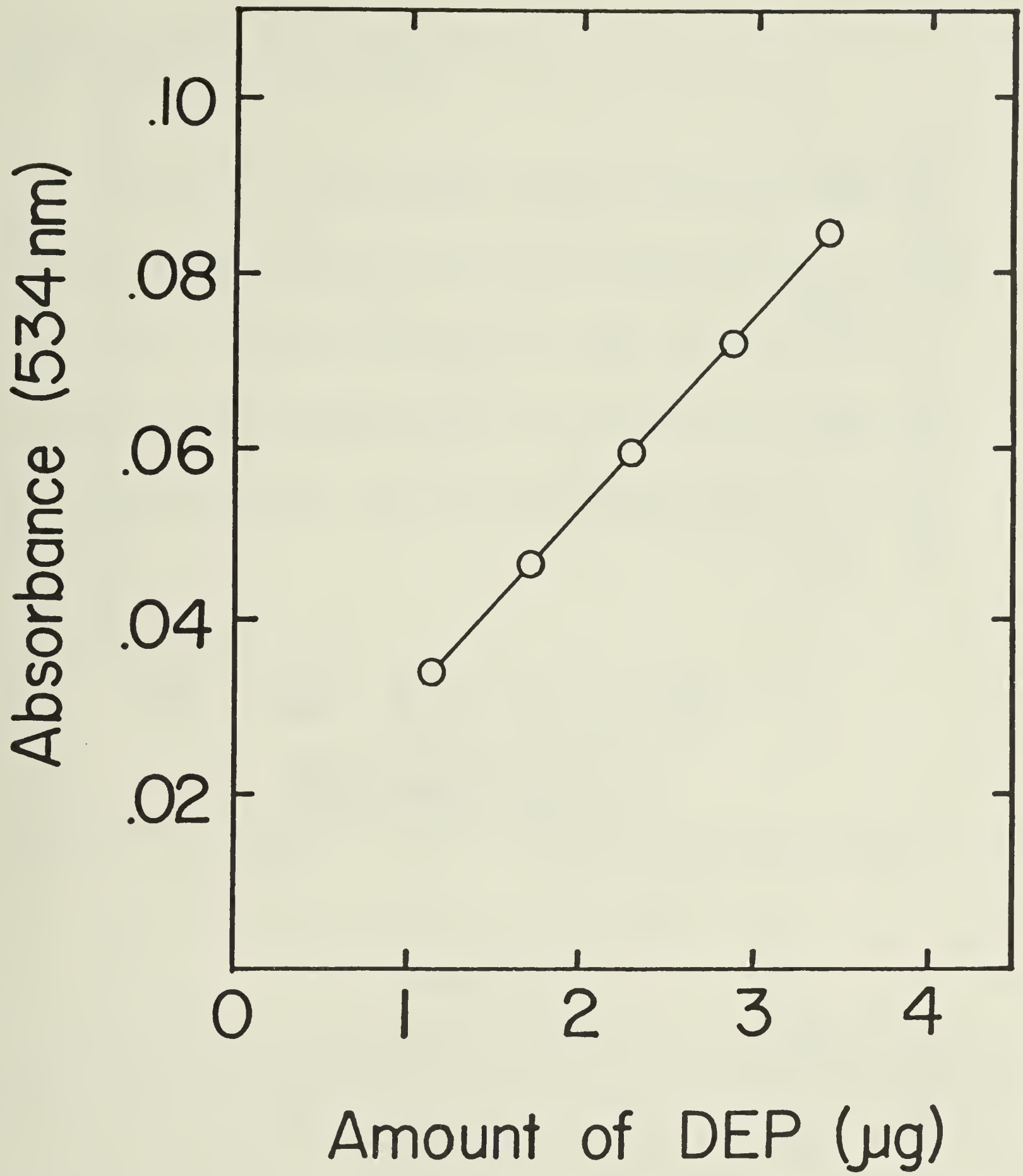

Fig. 1. Standard curve of prodigiosin analog synthesis with MBC and DEP. Amount of analog synthesized corresponds to its maximum absorption at 534 nm.

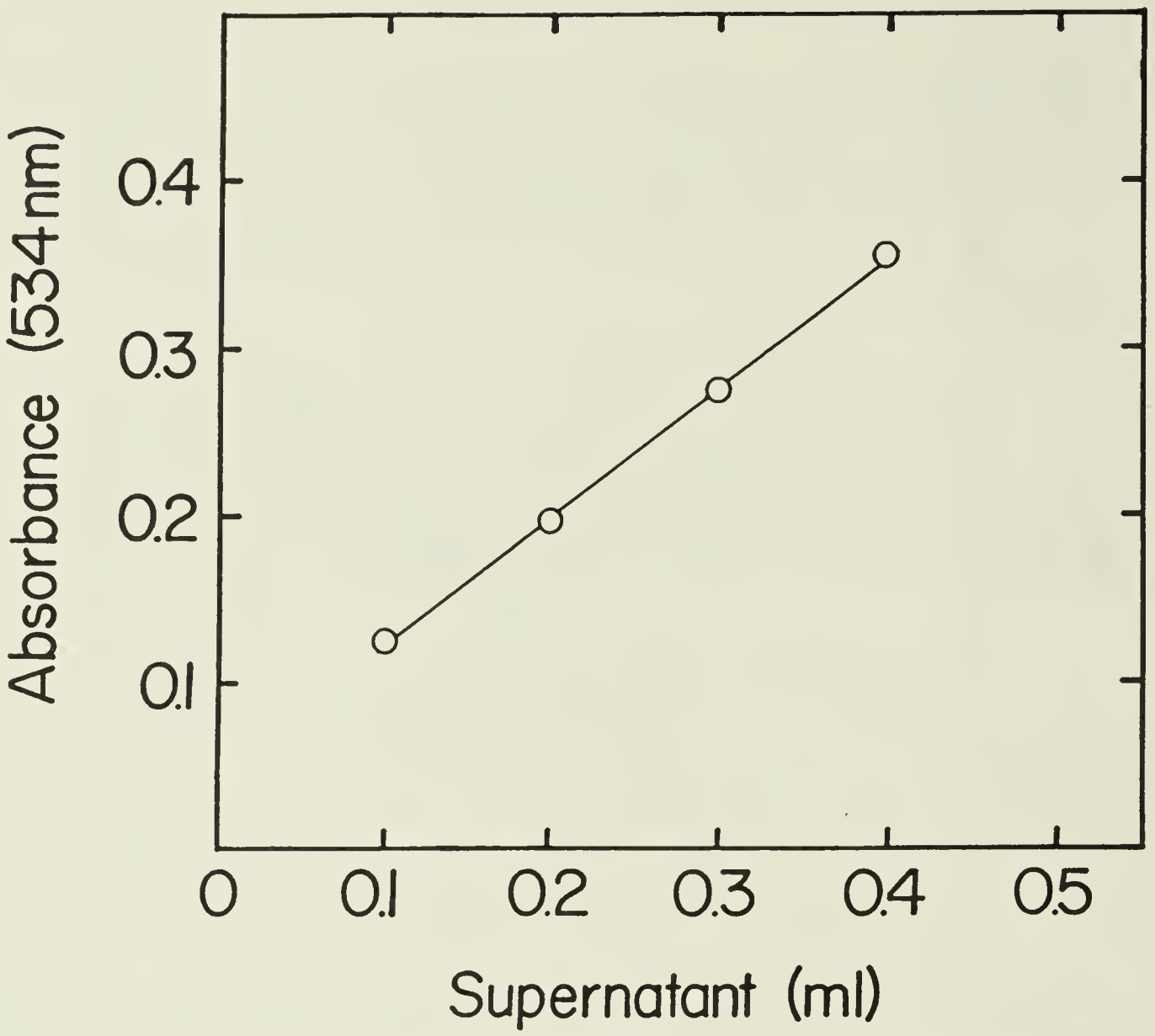

Fig. 2. The amount of MAP in the culture medium of mutant WF was measured by the absorbance at 534 nm of the prodigiosin formed.

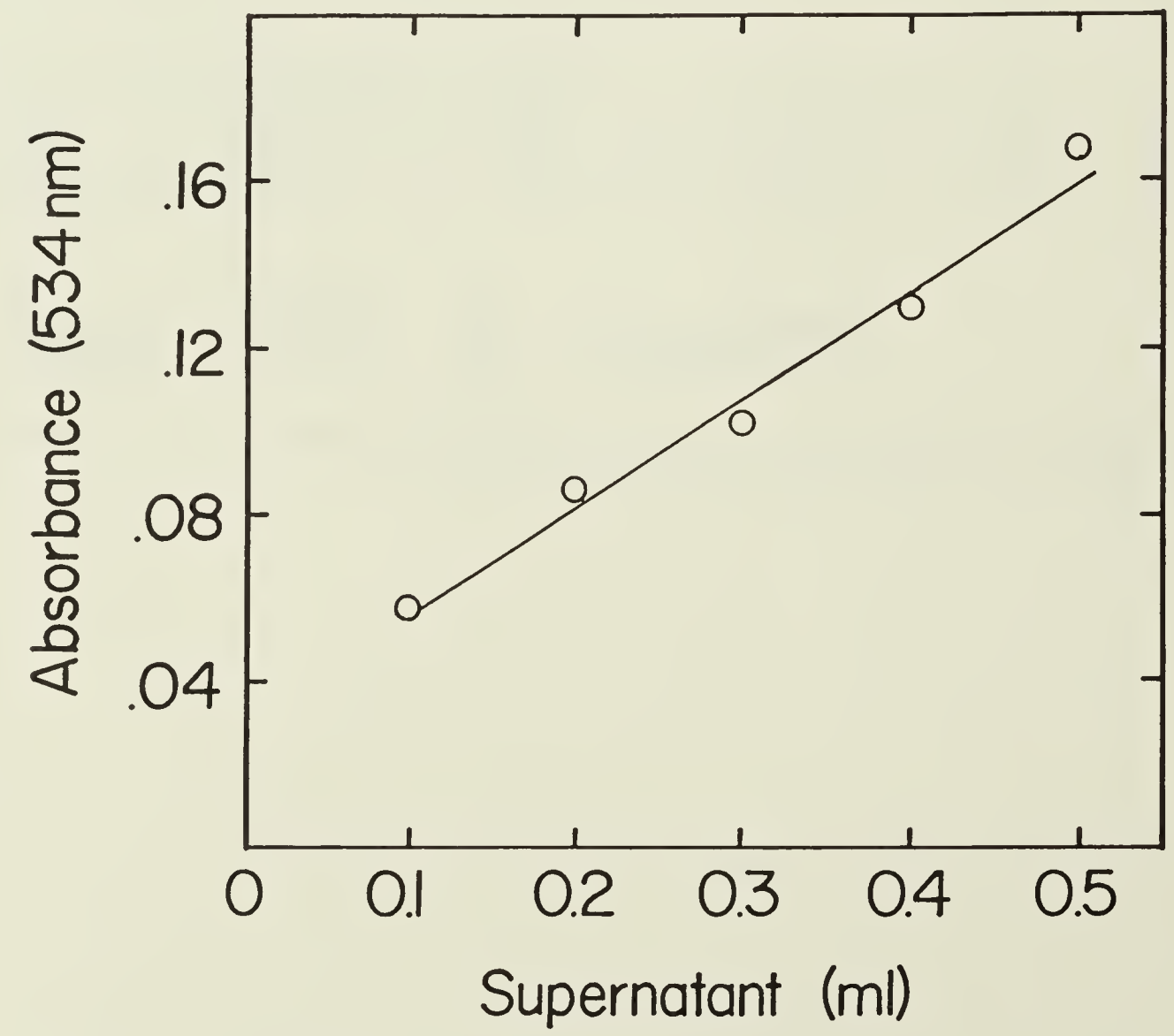

Fig. 3. The amount of MAP in the culture medium of mutant WF in the presence of Zn(II) was measured by the absorbance at 534 nm of the prodigiosin formed.

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EFFECT OF PH AND TOTAL ION CONCENTRATION ON GROWTH RATE OF *CHIRONOMUS* NR. *MATURUS* LARVAE (DIPTERA: CHIRONOMIDAE) FROM AN ACID STRIP-MINE LAKE

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ABSTRACT

Larvae of *Chironomus* nr. *maturus* Johannsen, a species abundant in an acid (pH 3) strip-mine lake, were raised in the laboratory in sixteen solutions combining pH's of 3.2, 4.0, 5.0, and 6.6 with total ion concentrations of 2670, 1350, 690, and 30 mg/1. Larval growth rate was significantly lower at pH 6.6 than at the three lower pH's, suggesting that a low pH is optimal for this species. Larval growth rate was unaffected by total ion concentration.

INTRODUCTION

Lakes on strip-mined areas are often chemically distinctive: In Illinois about six percent are very acid, with a pH less than 4.5 (Haynes and Klimstra 1975), and most, whether acid or not, have a considerably higher total ion concentration than other lakes (Konik 1980). Chemical conditions can affect the composition and abundance of the fauna living in a lake, following Thienemann's second ecological principle: "The more the conditions in a locality deviate from normal, and hence from the normal optima of most species, the smaller is the number of species which occur there and the greater the number of individuals of each of the species which do occur" (Hynes 1970, p. 234, citing Thienemann 1954). The abundance of species in acid

waters with a high ion concentration does not necessarily mean that this environment is optimal for them; their abundance could simply result from the absence of predation and ability of the species to tolerate conditions far below their optimum. In one acid strip-mine lake in southern Illinois, Bradley's Acid Pit, only two species of Chironomidae occurred, but the larvae were abundant, each with as many as 50,000 larvae/m^2 (Zullo 1981). This situation offered an opportunity to determine whether or not larvae in this lake are stressed by the low pH and high total ion concentration.

One of the species appears to be identical to *Chironomus maturus* Johannsen in larval, pupal, and adult stages as described by Sublette and Sublette (1974) but differs in the banding pattern of the giant chromosomes, so has been designated *C.* nr. *maturus* (Yamamoto 1977). From August 1977 to May 1978 the pH of Bradley's Acid Pit ranged from 2.70 to 3.85, and conductivity from 1085 to 3111 μmhos at 25°C except for one measurement of 35,943 μmhos in March 1978 (Zullo 1981). In this lake μmhos are equal to mg/liter total ion concentration (Stahl, unpublished). Sulfate varied from 800 to 1950 mg/liter except for two anomalous values.

The question is: even though the population of *C.* nr. *maturus* in Bradley's Acid Pit is high, are the larvae being stressed by either the low pH or the high ion concentration? To answer this question, growth of larvae in a range of pH's and total ion concentrations was measured.

METHODS

Sixteen solutions were made up with $CaSO_4$, $MgSO_4$, Knop's solution and phosphoric acid buffer, with combinations of four different pH's and four different total ion concentrations, namely, pH 3.2, 4.0, 5.0, and 6.6, and total ion concentrations in mg/l of 2670, 1350, 690, and 30. The aim was to make up simplified solutions having ratios of major ions similar to those in Bradley's Acid Pit water. The Ca^{++}:Mg^{++} weight ratio was kept at 1.3:1. The desired pH was obtained and maintained with 1 N HCl and 1 N NaOH, and the desired total ion concentrations with $CaSO_4$ and $MgSO_4$ as well as 14 mg/l Knop's solution and 16 mg/l phosphoric acid buffer in each 900 ml of water. Knop's contains 1 mg/l K^+ and 8 mg/l NO_3^- (Beers 1959). Originally we wanted solutions with a pH of 3.0 and 7.0, but solubility problems developed at those pH's. Total ion concentration and the concentration of Ca^{++}, Mg^{++}, and SO_4^{--} in each solution were, respectively: 2670 (420, 222, 2000); 1350 (212, 112, 1000); 690 (107, 58, 500); 30 (2, 1, 2).

The solutions were poured into one-liter mason jars having 1 cm of clean sand on the bottom. Each jar received 1.8 mg of methylene blue as a fungicide (Thornton and Wilhm 1974). The jars were kept in a water bath at a temperature of 20.5 ± 1.5°C and were continuously aerated.

Each jar received 65 to 90 eggs of *C.* nr. *maturus*, collected from Bradley's Acid Pit. If all eggs hatched, larval population density would have been 7190 to 9960/m^2. Larvae were fed dog food (Hartz Rocky Mountain Dog Kisses®) at a rate of approximately 0.31 mg food per larva each day. Procedures generally followed those described by Biever (1965, 1971).

Three runs of the sixteen different solutions were made for a total of 48 jars. Jars were checked every 12 hours for signs of pupation and for pH. A Beckman Electromate pH meter with combination probe was used to measure pH. Sulfate was measured intermittently and at the end of each experimental run using the Hach

SulfaVer IV method (Hach Chemical Company, 1973). All solutions were checked at the end of each experimental run. When a pupa was found all larvae in that jar were then preserved in 10 percent formalin. Mortality was calculated by subtracting the number of live larvae, pupae, and pupal exuviae from the number of eggs placed in each jar. Total body length was measured with an ocular micrometer and wet weight with a Sartorius balance after blotting each larva for 30 seconds. All length and weight measurements were made within two days to minimize shrinkage and weight loss (Mackey 1977). Daily growth rates were calculated by dividing length and weight by the number of days in the larval growth period.

RESULTS AND DISCUSSION

Mortality as calculated was erratic (Table 1). Two-way ANOVA indicated no significant effects of either pH or total ion concentration on mortality (Table 2). Evidently much of the apparent mortality was caused by eggs not hatching, presumably because of infertility. It would have been better to have added newly hatched larvae to the experimental jars rather than the unhatched eggs. Analysis of variance of weighted means of length and wet weight showed that much of the variation was between the jars (MS value 0.0331) and little within each jar (MS value 0.0017). This implied that two-way ANOVA tests on the unweighted means of the growth rates would be more appropriate (Starks, pers. comm.).

A two-way ANOVA showed that length growth rate was significantly affected by pH but was not significantly affected by total ion concentration (Table 3). Analysis of the data on wet weight, the other measure of growth, confirmed this finding (Table 4). Analysis of the pH data by a modified Duncan's multiple range test showed that only at pH 6.6 were the growth rates in length and wet weight significantly different (Table 5). Since they were slower at pH 6.6 this implies that the more acid environments are more optimal for *C.* nr. *maturus* larvae. Thus this species seems not to be stressed by either the low pH or the high total ion concentrations characteristic of strip-mine lakes.

There have been a few studies of the effect of low pH on larval or nymphal mortality and emergence success in aquatic insects (Harp and Campbell 1967, Bell and Nebeker 1969, Bell 1970, and Bell 1971). The only chironomids evaluated were an undescribed species of *Chironomus* by Harp and Campbell (1967) (see Harp and Hubbard 1972 for a clarification of the identification) and *Tanytarsus dissimilis* Johannsen by Bell (1970). Emergence of *C.* sp. was inhibited by a pH of 2.8 to 3.0, and all larvae of *T. dissimilis* died in 5 to 10 days at pH's of 3.0 and 4.0. To our knowledge there are no other studies of the effects of pH on growth rates of chironomid larvae. Indeed, apparently only Fiance (1978) measured growth rate in an aquatic insect at low pH. In a section of stream acidified to pH 4 for three months the larvae of the mayfly *Ephemerella funeralis* were 29 per cent smaller than in the reference section of the stream. In all the studies cited the effect of low pH was adverse. However, none of these studies used our approach of testing the response to higher pH's of a species found in an acid environment. Our approach might reveal other species that are favored by the low pH of acid strip-mine lakes. In Bradley's Acid Pit the other abundant chironomid species, *Tanytarsus dendyi* Sublette, is known from circumneutral water (Buckley and Sublette 1964), so it might either be favored or inhibited by a highly acid environment.

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Table 1. Percent mortality of *C.* nr. *maturus* larvae in experimental solutions, runs 1, 2 and 3.

	Total ion concentration (mg/l)			
pH	2670	1350	690	30
3.2	11, 100, 40	13, 93, 25	96, 100, 44	86, 43, 15
4.0	11, 100, 17	15, 100, 11	97, 65, 60	58, 100, 24
5.0	12, 20, 16	6, 35, 41	21, 87, 40	28, 10, 0
6.6	100, 70, 35	9, 38, 27	11, 7, 77	31, 53, 43

Table 2. Two way ANOVA of the effects of pH and total ion concentration on mortality of *C.* nr. *maturus* larvae grown in experimental solutions.

Source	df	SS	MS	F value
Model	15	17,168	1,144	1.04[a]
pH	3	3,810	1,270	1.15[a]
total ion concentration	3	6,783	2,261	2.05[a]
pH × total ion concentration	9	6,573	730	0.66[a]
Error	32	35,383	1,105	
Total	47	52,551		

[a]Not significant at the 0.05 level.
df = degrees of freedom
SS = sum of squares
MS = mean square
F = variance ratio
Identical abbreviations are to be found on Tables 3 and 4.

Table 3. Two way ANOVA of the effects of pH and total ion concentration on the unweighted means of the length growth rate (mm/day) of *C.* nr. *maturus* larvae in experimental solutions.

Source	df	SS	MS	F value
Model	8	0.1220	0.0152	6.75***
replicate	2	0.0150	0.0075	3.33
pH	3	0.1086	0.0362	16.03***
total ion concentration	3	0.0034	0.0011	0.51
Error	33	0.0745	0.0023	
Total	41	0.1965		

***Significant at the 0.001 level.

Table 4. Two way ANOVA of the effects of pH and total ion concentration on the unweighted means of the wet weight growth rate (mg/day) of *C.* nr. *maturus* larvae in experimental solutions.

Source	df	SS	MS	F value
Model	8	0.000040	0.000005	3.44***
replicate	2	0.000005	0.000003	2.55
pH	3	0.000030	0.000010	7.09***
total ion concentration	3	0.000005	0.000002	0.92
Error	33	0.000050	0.000001	
Total	41	0.000090		

**Significant at the 0.01 level.
***Significant at the 0.001 level.

Table 5. Analysis by a modified Duncan's multiple range test of the effect of pH on unweighted means of length growth rate (mm/day) and wet weight growth rate (mg/day) of *C.* nr. *maturus* larvae in experimental solutions.

		Growth rate	
pH	No. observations	Length Mean*	Wet weight Mean*
3.2	10	0.3225[a]	0.1380[a]
4.0	9	0.3401[a]	0.1280[a]
5.0	12	0.3243[a]	0.1250[a]
6.6	11	0.2164[b]	0.0740[b]

*Means with the same letter are not significantly different at the 0.05 level.

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SUMMER FEEDING HABITS OF BARN OWLS (*TYTO ALBA*) FROM WHITE COUNTY, ILLINOIS

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ABSTRACT

Prey remains are described from a 4-month accumulation of pellets from a nesting pair of barn owls. Of 233 individual prey items, 163 (73.1%) were microtines, primarily prairie voles and pine voles. The minimum estimated daily mean biomass consumed by each owl was 49.8 g per day.

INTRODUCTION

Population densities of the barn owl (*Tyto alba*) are declining, and the species is classified as endangered in Illinois. The only breeding records of the barn owl in the state are pre-1975 for Jefferson, Wayne and Hamilton counties (Natural Land Institute, 1981). Information on the feeding habits of this species in Illinois is minimal; the only previous data were those of Cahn and Kemp (1930). This paper describes prey remains found in cast pellets deposited from approximately May through August 1984 by a breeding pair of barn owls. The nest was found in April 1984. Five owlets subsequently fledged; the last died of inanition (A. Woolf, pers. commun.).

METHODS

All pellets were collected on 27 August 1984 from a farm silo near Norris City, White County, Illinois. The total number of pellets was not estimated, as many were broken, poorly formed or pieces were clumped together. All pellets were separated by hand and skeletal remains extracted. Differentiation of prairie voles (*Microtus ochrogaster*) and pine voles (*M. pinetorum*) was based on characteristics of the anterior enamel border of the fourth triangle of the first lower molar (see Martin, 1974; Martin and Webb, 1974). Frequency of each prey species was based on the

largest number of one identifiable part, either the skull, right or left mandible. An average weight for each prey species was estimated from Marti (1974), Steenhof (1983) and specimens in the Southern Illinois University-Carbondale mammal collection. An estimated mean body weight for undetermined shrews, mice and voles was calculated as a weighted average of the known percentage of each species in each taxon. For example, *M. ochrogaster* (mean body weight = 30g) comprised 62.2% of identifiable *Microtus*, and *M. pinetorum* ($\bar{x}$ = 24g) comprised 37.8%. Thus, the estimated mean weight of the undetermined *Microtus* (n = 56) was calculated as: (56 × .622) 30 + (56 × .378) 24/56 = 27.7 g. A similar procedure was used for the undetermined shrews and mice. No adjustment was made for differences in mean body weight due to age or sex. Thus, biomass calculations, if biased, are probably slightly high.

RESULTS AND DISCUSSION

A total of 223 bird and mammal prey remains was found (Table 1). Mammals comprised 96.0% of the remains by frequency and 91.8% of the biomass. Birds made up the remaining food items. No invertebrate, fish, amphibian or reptile remains were found. The majority of mammalian prey consisted of microtines, specifically prairie voles and pine voles, (69.1%), with the bog lemming (*Synaptomys cooperi*) contributing an additional 4%. Together, microtines comprised 76.0% of the total biomass consumed by the owls. *Microtus* sp. are generally abundant in southern Illinois. Although the frequency of microtines in barn owls diets probably fluctuates relative to their cyclic availability, many other studies of barn owl feeding habits have found *Microtus* as the primary prey item (Smith et al., 1972; Marti, 1974; Smith and Marti, 1976; Dawe et al., 1978). Mice (*Peromyscus* sp. and *Mus musculus*) were relatively intermediate in frequency, comprising 12.6% of prey items. Much less common in pellet remains was the eastern mole (*Scalopus aquaticus*), which comprised 0.9% of the food items by frequency, and 2.5% by biomass. Although moles (*Talpa europaea*) are abundant in Britain, Glue (1974) found they comprise less than 1% of the biomass of barn owl prey. In Poland, Ruprecht (1979:499) considered moles a "chance component" of barn owl diets. Moles preyed upon by barn owls are usually taken in summer months (Bunn et al., 1982), and probably are dispersing subadults (Giger, 1965). One skull of a rice rat (*Oryzomys palustris*) was found comprising just 0.4% of the prey items. This species, uncommon in southern Illinois (McLaughlin and Robertson, 1951; Klimstra and Scott, 1956), is considered threatened (Natural Land Institute, 1981). These findings suggest the owls were not foraging selectively, but took prey opportunistically, probably in proportion to availability. Several previous studies also have concluded that barn owls do not forage selectively (Ticehurst, 1935; Bunn et al., 1982).

The estimated biomass of prey consumed by the pair of barn owls during the approximate 120-day period was 5,971 g (Table 1). This probably represents only about one-half the total intake during this period. Barn owls generally cast two pellets per 24-hour period (Guerin, 1928 from Evans and Emlen, 1947; Marti, 1973); one pellet is dropped somewhere in the foraging area, the other at the roost site (Evans and Emlen, 1947). Because only about one-half the cast pellets were available for analysis, it is probable that approximately (5,971 × 2) = 11,942 g in prey biomass

was consumed by the two owls over 120 days, an average of 49.8 g/bird/day. Even allowing for possibly reduced metabolic demands during the warmer summer months, this is substantially less than the "normal" daily intake of barn owls of 100-150 g (Marti, 1970; Bunn et al., 1982). The calculated mean daily intake of biomass may have been too low if: 1) all pellets cast at the nest site from May through August were not found, or 2) some cast pellets had decomposed. Neither of these possibilities seems likely, however (K.A. West, pers. commun.). Lower estimated mean intake also may have been due to the hen not foraging during part of the 30-day incubation period (Wallace, 1948; Nice, 1954), both owls not remaining on the site throughout the 4-month period, or less than one-half the pellets being dropped at the nest site. Mean prey intake may have been less than 49.8g/bird/day if the owls were in the silo prior to May, which may have been the case (K.A. West, pers. commun.).

With the exception of *Peromyscus*, none of the small mammal species documented in Table 1 have been reported previously from White County (Hoffmeister and Mohr, 1957; Hoffmeister, manuscript in preparation).

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Table 1. Prey species of a nesting pair of barn owls in White County, Illinois, from May through August 1984.

Prey Item	Frequency	%	Estimated Mean weight (g)	Prey Biomass (g) (Frequency × mean wt.)
Mammals				
Insectivores				
Short-tailed shrew (*Blarina* sp.)	11	4.9	12.0	132
Least shrew (*Cryptotis parva*)	4	1.8	5.0	20
Undetermined shrew	5	2.3	10.0	50
Eastern mole (*Scalopus aquaticus*)	2	0.9	75.0	150
Rodents				
Prairie vole (*Microtus ochrogaster*)	61	27.4	30.0	1,830
Pine vole (*Microtus pinetorum*)	37	16.6	24.0	888
Undetermined vole	56	25.1	27.7	1,553
Deer mice (*Peromyscus* sp.)	14	6.3	20.0	280
Bog lemming (*Synaptomys cooperi*)	9	4.0	30.0	270
House mouse (*Mus musculus*)	9	4.0	18.0	162
Undetermined mice	5	2.3	19.2	96
Rice rat (*Oryzomys palustris*)	1	0.4	50.0	50
SUBTOTAL MAMMALS	214	96.0		5,481
Birds				
Red-winged Blackbird (*Agelaius phoeniceus*)	7	3.1	55.0	385
Grosbeak (?)(Fringillidae)	1	0.4	75.0	75
Small passerine	1	0.4	30.0	30
SUBTOTAL BIRDS	9	3.9		490
TOTALS	223	99.9		5,971

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INCISOR MALOCCLUSION IN A SPECIMEN OF SYLVILAGUS FLORIDANUS MEARNSII (MAMMALIA, LAGOMORPHA) FROM ILLINOIS

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Overgrowth of incisors or malocclusion has been reported in wild lagomorphs on only two occasions. Gregory (1952) reported an incidence of hypertrophism in a wild specimen *Sylvilagus floridanus mallurus*, in which the left lower incisor extended nearly three centimeters beyond the end of the jaw, curving abruptly upward in front of the snout.

Woodyard (1981) described a malocclusion in which the lower left incisor extended 1.8 cm beyond the mandible, while the lower right incisor extended 2.5 cm beyond the mandible and curved to the left.

A female (NUVC 5227), Fig. 1-2, *Sylvilagus floridanus mearnsii* having been caught by a feral house cat, *Felis catus* in East Dundee, Kane County, Illinois, was brought to my attention by Mrs. Vera Shumilak. At the time of capture on 6 June 1983, the specimen was gravid, containing five near term embryos, and appeared in healthy condition, suggesting that it was able to obtain nutrition for normal growth dispite its inability ot use its incisors. The lower left incisor extended 3.6 cm beyond the mandible. The lower right incisor extended 0.3 cm beyond the mandible, but had been broken off prior to capture. The tip of the left incisor was rounded and smooth, while the tip of the right incisor was jagged. Both incisors appeared to be correctly positioned relative to the symphysis of the mandibles.

The upper left incisor extended 1.3 cm from the premaxillary and had grown into a short arc. The smaller incisor was nearly of equal length and in correct lateral position to the larger one. The upper right first incisor extended 1.4 cm from the premaxillary and had grown in an arc of approximately 180 degrees, offset 0.6 cm to the right of the premaxillary symphysis. The smaller incisor extended 0.6 cm from the premaxillary and was in normal position.

The premolars and molars appeared normal. There were no indications of any fractured or malformed bones.

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Gregory, Joseph T. 1953. Incisor Malocclusion in a Cottontail Rabbit. Jour. Mammal. 34(3):393-4.
Woodyard, Gary W. 1981. Incisor Malocclusion in a specimen of *Sylvilagus floridanus* (Mammalia: Lagomorpha) from North Carolina, Brimleyana 7:151-153. Fig. 1.

Fig. 1. Left lateral view of skull and mandible showing extreme development of upper and lower incisors. 2x natural size.

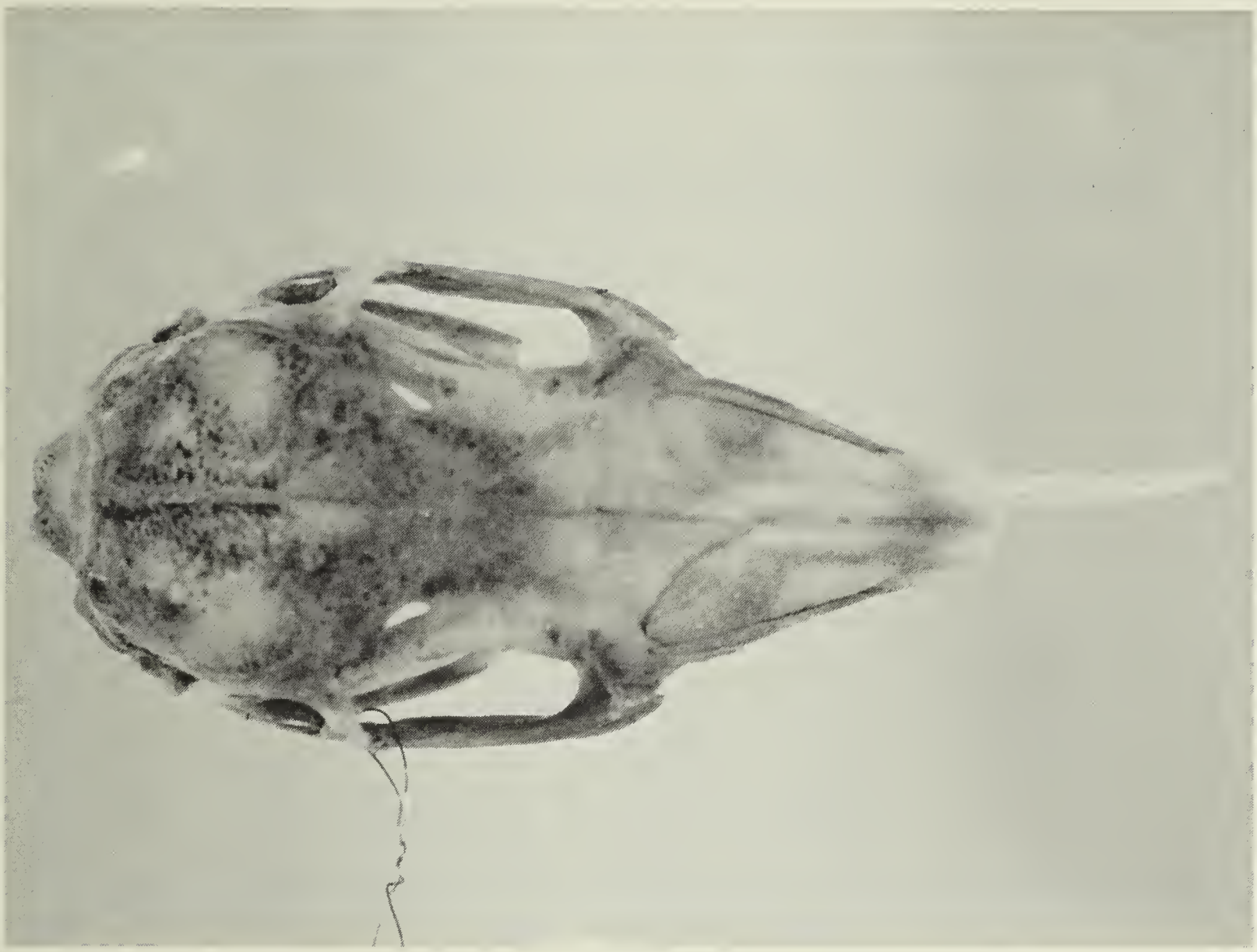

Fig. 2. Dorsal view of skull showing left lower incisor, and normal development of skull. 2x natural size.

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A COMPARISON OF HEAT ENERGY MODELS BETWEEN SCARLET OAK (*QUERCUS COCCINEA*) AND BLACK OAK (*QUERCUS VELUTINA*)

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ABSTRACT

Twenty scarlet oak (12) and black oak (8) trees were analyzed to determine the effect of age, specific gravity, size and height on the heat energy output. The two species had the same specific gravity and the same heat energy content. However, the effect of diameter, height, age and specific gravity on heat energy did vary between the two species.

INTRODUCTION

Wood is among the oldest sources of energy known to man, being used for over 500,000 years (Sharpe, 1976). The single largest use of wood in the world is for fuel. The less industrialized countries utilize between 70 to 95 percent of their annual harvest of roundwood for energy (Chow, 1977). Fifty percent of all wood harvested internationally is used for fuel (Karchesy and Koch, 1979).

According to Smith and Dowd (1981) approximately 14 percent of the world's heat energy consumption comes from wood, whereas only two percent of the United States' total energy requirements is supplied by wood. However, for the past ten years, an increasingly large number of Americans have been using wood energy in their homes as an alternative or a supplement to oil, gas or electricity. In 1973, there was approximately 200,000 wood stoves in use in the United States (Smith and Dowd, 1981). By 1978, however, there were approximately 5 million house-

holds with a working wood stove and approximately 18 million households with a working fireplace. An estimated 7.5 million cords of fuelwood were consumed in 1976 compared to 10 to 20 million cords in 1979 (Wood Energy Institute, 1979). These fuelwood consumption figures can be contrasted to the 1979 domestic roundwood production of 152 million cords.

Because of this increasing demand, some forest landowners are considering emphasizing fuelwood production by favoring those tree species with the greatest energy output. Therefore, the objective of this study was to determine the effect of a tree's age, specific gravity, size and height on the energy output. Energy output was expressed in terms of BTU per pound of oven-dry weight. Two common fuelwood species, scarlet oak and black oak, in southern Illinois were chosen for study.

MATERIALS AND METHODS

The sample trees (12 scarlet oaks and 8 black oaks) were collected from a half-acre of a native central hardwood stand located in the Shawnee National Forest, Illinois (Njiti, 1984). The diameter at breast height (d.b.h.) of the trees ranged from 1.7 to 9.0 inches and the height ranged from 17 to 53 feet.

After the trees were cut, sample disks were taken at stump height, at breast height, and at 1″ and 0.5″ diameter outside bark (Figure 1). Disks were also cut at every 2-inch diameter interval. Distances from the ground level to each disk were recorded. There were 65 disks from scarlet oak and 52 from black oak trees.

Laboratory analysis included determination of specific gravity by the water displacement method and age determination by counting the number of rings from pith to bark. Each disk was chipped separately with a band saw and sampled chips were ground to powder size smaller than 0.5 mm.

After the samples were oven-dried, they were pressed into pellets of approximately 1.0 gram using a press. The pellet formation was necessary to avoid the powder from being blown about during combustion. The combustion process was carried out within an adiabatic oxygen bomb calorimeter charged with thirty atmospheres pressure of oxygen.

An initial temperature in the calorimeter was recorded when five consecutive readings of the bucket and jacket temperatures were the same. Then the bomb was fired to ignite the charge. During this temperature rising period, heat transfer from the bucket to the jacket was prevented by admitting hot water into the jacket. The final temperature reading was recorded after there was no increase in the temperature readings. The heat energy of a sample was calculated as follows:

$$Hg = \frac{T \times W - N - F}{M} \times 1.8$$

Where

Hg = Gross heat of combustion in Btu/lb.
T = Temperature rise, or final temperature minus initial temperature in °F.
W = Energy equivalent of calorimeter, 1363 cal./°F.
N = Correction in heat of formation of nitric acid.
F = Correction for heat of combusion of Platinum fuse wire.
M = Mass of sample in grams
1.8 = Conversion factor from cal/gr. to Btu/lb.

RESULTS AND DISCUSSION

Comparison Between Mean Btu Values

There was no statistically significant difference between the mean Btu for scarlet oak (8,337) and for black oak (8,334). These findings were partially due to the lack of difference in the average specific gravity in scarlet oak (0.61) and black oak (.62). The similarity of specific gravity in two species can be interpreted as similarity in i) the size of cell, ii) the thickness of cell walls, and iii) the extractive content of wood. Since these factors influence Btu output, wood with similar specific gravity would have similar Btu values.

Comparison Between Btu Models

Although there was no significant difference in mean Btu between the two species, the models of Btu were different:

Scarlet oak. The combined effects of diameter, age, specific gravity, and height on Btu were significant and the R^2 was 18 percent. When each of the variables was tested for the effects of their partial contribution to Btu, the effect of diameter was significant while age, specific gravity, and height had no significant effects. The simple regression analysis also produced similar results except that the effect of diameter was significant not only at the .05 level but also the .01 level. There was no significant interaction effects.

Black Oak. The full model of the independent variables had a significant effect on Btu; R^2 was 19 percent. For partial contribution to Btu, the effect of age was significant (.01 level) and the effect of height was also significant. However, in the simple regression test, the effects of both age and height were non-significant. The interaction test showed that diameter, age, specific gravity, and height did not have any significant interaction effects between them.

Comparison of Disk Location

On both species, there was significant difference between Btu measurements on disks located at stump and at d.b.h. However, the direction of differences was not the same for the two species. In scarlet oak, the stump disk had a higher heat energy (38 Btu) than the d.b.h. disk. But in black oak, the d.b.h. disk had a higher heat energy (118 Btu) than the stump disk.

Disks with 1/2 inches diameter had higher Btu than disks at stump for both species. The half-inch disks also had higher Btu than one-inch disks and d.b.h. disks in scarlet oak but not in black oak (Table 1).

Disks with 1/2 inches diameter should contain more juvenile wood than mature wood, while the reverse would be true for the stump disks. Our study agreed with the previous study in sycamore that juvenile wood yielded a greater heat value than mature wood (Chow, et. al. 1980).

CONCLUSION

The objective of this study was to determine the effect of a tree's age, specific gravity, size, and height on the heat energy output. Twenty trees (12 scarlet oaks and 8 black oaks) located within the Shawnee National Forest in southern Illinois were analyzed. The major conclusions were:

1. Scarlet oak and black oak generally have the same specific gravity (0.61) and the same heat energy content (8,336 Btu). Wood with similar specific gravity should have similar heat value.
2. Although the mean specific gravity and the mean heat value are similar in the two species, the effect of diameter, height, age and specific gravity of each sample on its heat value may vary from species to species.
3. Because the heat value of wood varies with the position of the sample taken, the trend is not linear from stump to branches. Furthermore, the position effect may vary among species. Therefore, samples from a fixed position may not provide a valid comparison between species. Whole tree sampling would be more suitable for heat value study.

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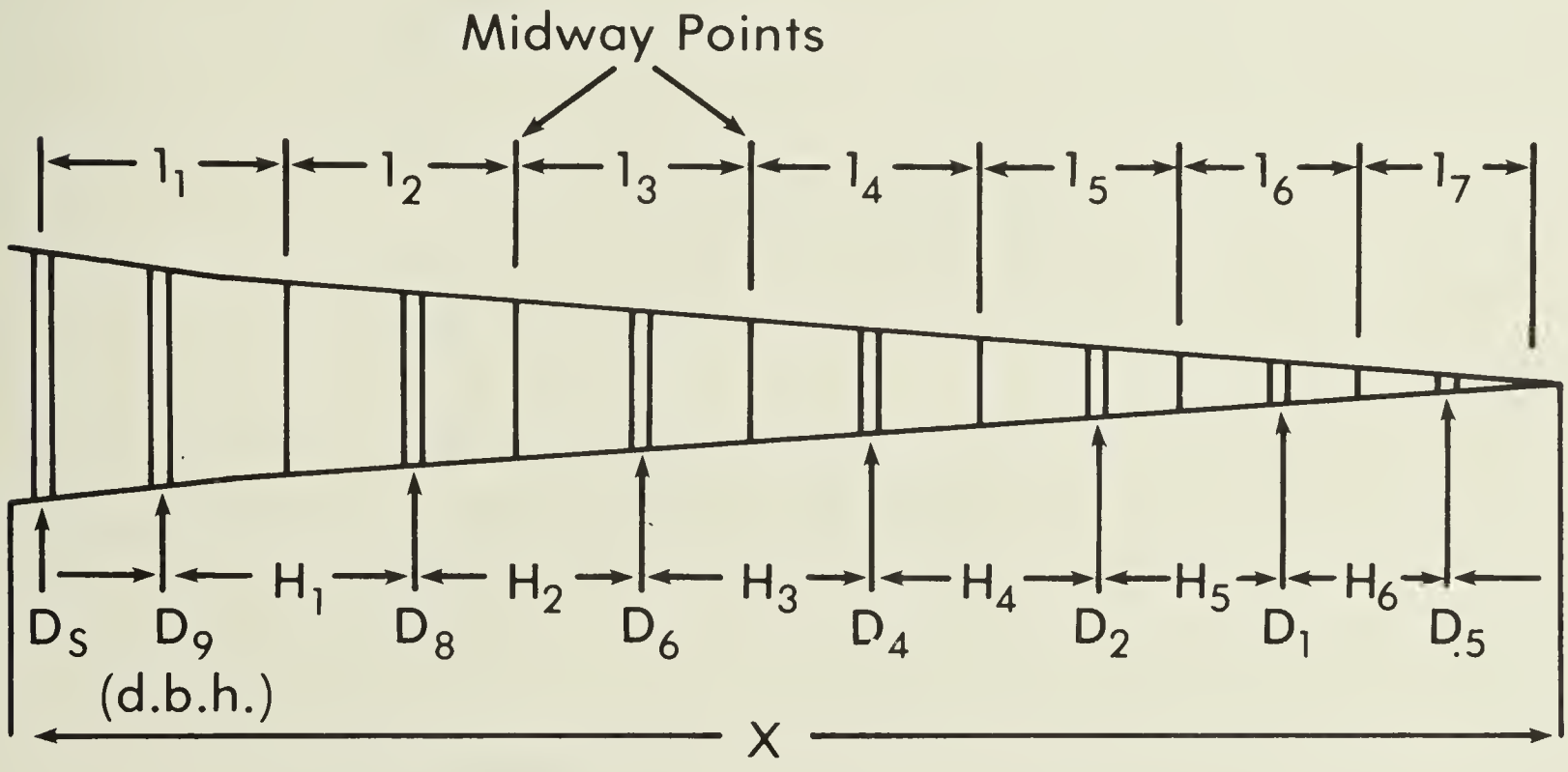
Table 1. Comparison of the Btu Contents from the Base to the Top of the Tree by Species.

Diameter Contrast	T-Value	Level of Significance
a. *Black oak*		
Stump vs. d.b.h.	4.15	.01
Stump vs. 1 inch	1.75	non-significant
Stump vs. 1/2 inch	2.28	.05
d.b.h. vs. 1 inch	1.72	non-significant
d.b.h. vs. 1/2 inch	0.89	non-significant
One inch vs. 1/2 inch	0.87	non-significant
b. *Scarlet oak*		
Stump vs. d.b.h.	1.82	.05
Stump vs. 1 inch	0.77	non-significant
Stump vs. 1/2 inch	2.02	.05
d.b.h. vs. 1 inch	0.37	non-significant
d.b.h. vs. 1/2 inch	3.70	.01
One inch vs. 1/2 inch	3.81	.01

Fig. 1. Schematic of Sample Disk Layout for a Nine-inch Tree.



D_S = stump diameter

D = disk location; subscripts stand for disk diameter in inches

X = total height of tree

H = height between sample disks

l = length of truncated cone; subscripts denote cone number

ERRATUM

The Editor and Publisher regret the poor photograph quality in certain articles published in Volume 77, *Transactions*. They are reproduced on the following pages. An additional ERRATUM will be published later this year.

SPIRIFERELLINA LATA LANE IN THE UPPERMOST CHESTERIAN IN THE BIRD SPRING GROUP AT ARROW CANYON, CLARK COUNTY, NEVADA.

Daniel W. Petersen and Ralph L. Langeheim, Jr.
Department of Geology
University of Illinois
Urbana, Illinois 61801

Figs. 4-8. Hypotype A6353, X1.

4. Dorsal exterior
5. Ventral exterior
6. Posterior
7. Anterior
8. Lateral

Figs. 9-11. Hypotype A6354, X1, alate pedicle valve.

9. Exterior
10. Interior
11. Lateral

Fig. 12. Hypotype A6355, X1, pedicle valve rounded posterior.

Figs. 13-15. Hypotype A6356, X1, brachial valve.

13. Exterior
14. Interior
15. Lateral

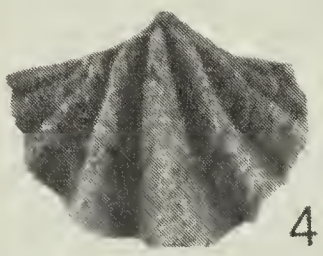
Figs. 16-20. Hypotype A6357, *Spiriferellina lata* with preserved spines.

16. Pedicle exterior X4
17. Pedicle exterior X2
18. Pedicle interior with short septum X2
19. Brachial exterior X2
20. Brachial interior X2

Fig. 21. View of micro-ornamentation of hypotype A6354, X6.

Fig. 22-23. Hypotype A6358, X1 pedicle valve with long septum.

22. Interior
23. Exterior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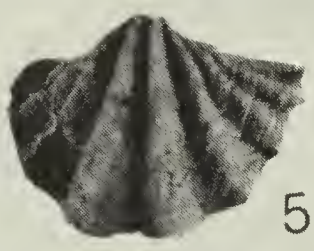
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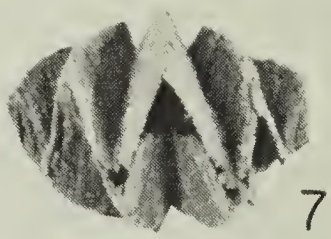
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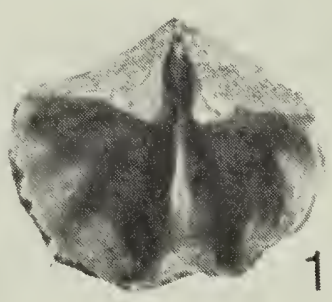
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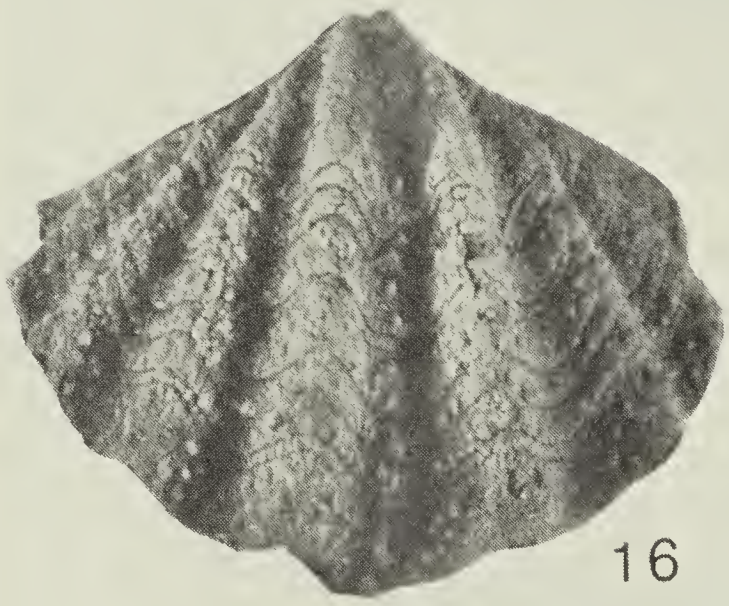
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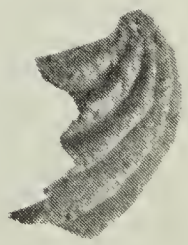
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SURFACE FEATURES OF *TETRAHYMENA ROSTRATA* AS VIEWED WITH SCANNING ELECTRON MICROSCOPY

Eugene W. McArdle
Department of Biology
Northeastern Illinois University
Chicago, IL 60625

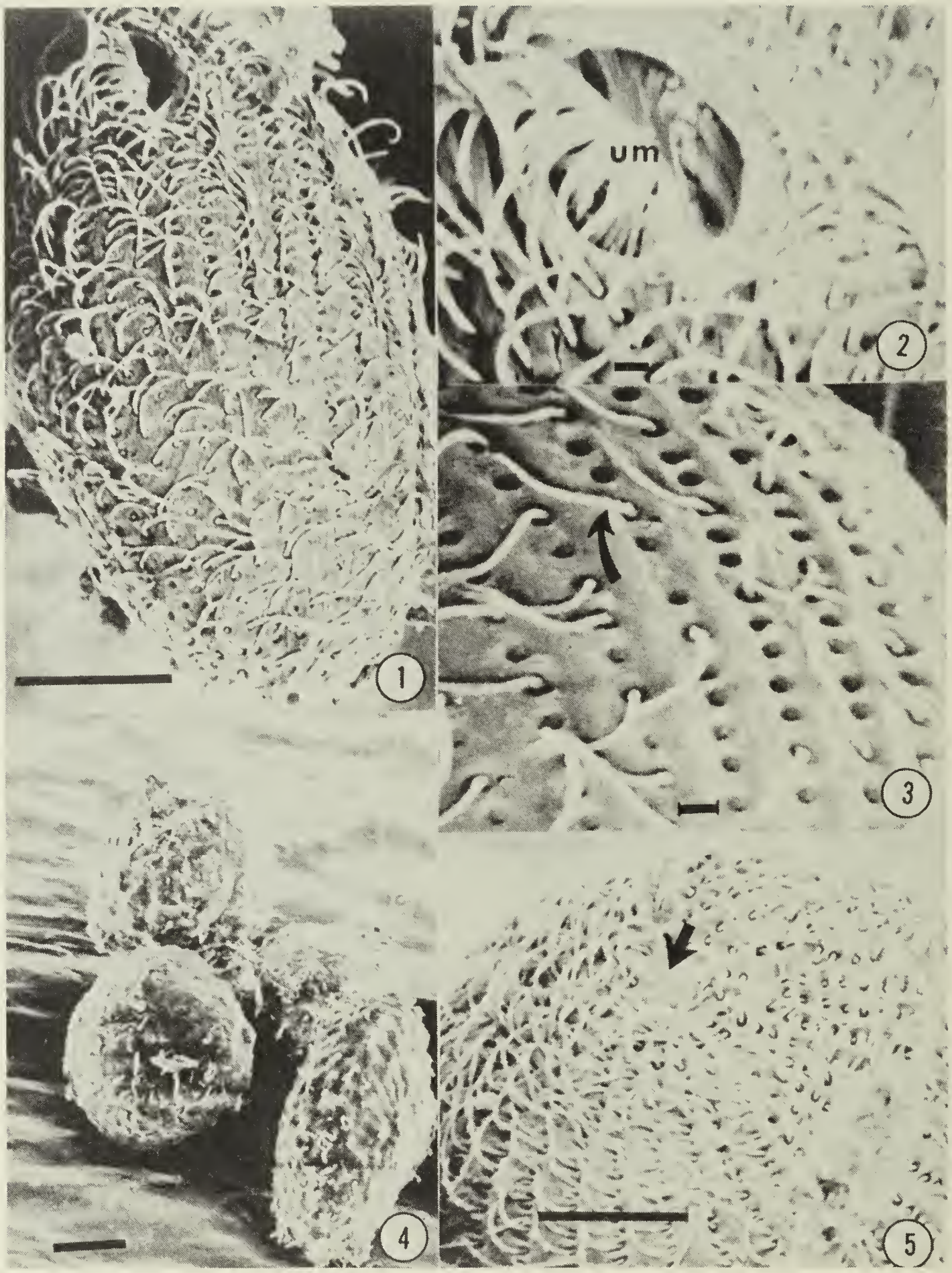

Fig. 1. Ventral view of a trophont of *T. rostrata* showing the subterminal position of the buccal overture at the anterior end and the holotrichous arrangement of the ciliary rows. The opaque material at the periphery of the organism is likely agglomerated mucoid material secreted by the organism's mucocyst organelles. The scale bar indicates 10 μm.

Fig. 2. The buccal overture is depicted at higher magnification. It shows the position of the undulating membrane (um) on the organism's right side of the buccal opening. The oral area is surrounded by somatic ciliation. The scale bar indicates 1 μm.

Fig. 3. A partially de-ciliated surface of a trophont. The cilia that remain (arrow) are relatively uniform in size and emerge from aveolar depressions in the cortex. The scale bar indicated 1 μm.

Fig. 4. Four encysted individuals of *T. rostrata*. The secreted cyst wall is uneven and irregular in its appearance but conforms to the general shape of the organism within. The small, light-colored rods on the surface are environmental bacteria adhering to the outer face of the cyst wall. The scale bar represents 10 μm.

Fig. 5. A view of the posterior end of a trophont showing the convergence of the ciliary rows and the location of a characteristic polar cilium (arrow). The scale bar denotes 10 μm.

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(1985), Volume 78, 3 and 4, pp.

REVIEW ARTICLE

A REVIEW OF COAL DESULFURIZATION

Robert C. Duty
Chemistry Department
Illinois State University
Normal, Illinois 61761

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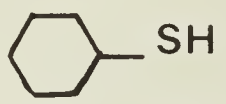
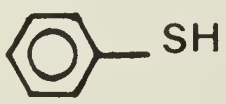
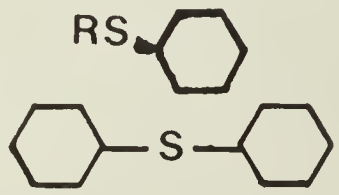
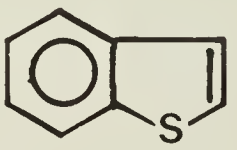
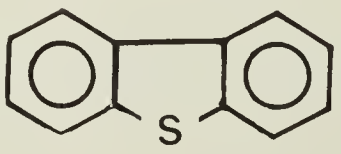
A REVIEW OF COAL DESULFURIZATION

INTRODUCTION

Sulfur in coal is present in both organic and inorganic forms and ranges from 0.5 to 8% by weight in a coal seam (Greer, 1977). Inorganic sulfur is primarily in the form of pyrite (FeS_2), but small amounts of sulfite also are present. Meyers (1977) had listed a Table of coals (20 coals) from all the major producing regions of the world and reported a range of sulfur from 0.38% to a high of 5.32%. The pyritic sulfur in these selected coals ranged from 0.09% to a high of 3.97%.

Organic sulfur is found in coal in different functional groups and Given (1961) was the first to publish an extensive list of organic functional groups associated with coal. These are shown in the following Table 1.

Table 1. Organic Sulfur Species in Coal

Thiols	
a) alkyl	RSH
b) cyclic	
c) aromatic	
Sulfides	
a) alkyl	RSH
b) alkyl-cycloalkyl	
c) cyclic	
Disulfides	RS-SR
Thiophene	
Benzothiophene	
Dibenzothiophene	

Several years later Hayatsu *et al.* (1975) confirmed the benzothiophene and dibenzothiophene structures in coal by oxidation with dichromate where they isolated several aromatic acids of benzothiophene and dibenzothiophene.

In the desulfurization of coal, the most difficult form of sulfur to remove is the organic sulfur. The organic sulfur is partially removed by grinding the coal and washing it thoroughly with solvents.

This review of the desulfurization of coal will focus on the attempts that have been made to remove both inorganic and organic sulfur forms. Most of these methods have used an oxidation procedure, but later attempts have used elevated temperatures with alkali in organic solvents.

DESULFURIZATION VIA OXIDATION PROCEDURES

Weathering

Chakrabarti *et al.* (1982) was the first to report the organic desulfurization of coal by weathering or auto-desulfuration. He reported a decrease in organic sulfur from 2.29% to 1.87% (18% decrease) over a 4-year period. This same coal when ground (<63 um) continued to lose organic sulfur content and after an additional 228 days had dropped to 1.40%. The pyritic sulfur decreased 93% during the 4 years, but remained constant for the remaining 228 days.

The PETC Process

The PETC process (Pittsburgh Energy Technology Center) is one of the oldest desulfurization processes that was elevated to pilot plant scale at the TRW San Capistrano, CA location (Morrison, 1981a). This "oxydseulfurization" process utilizes air pressure at elevated temperatures with a wet coal slurry. A majority of the pyritic sulfur is removed along with a small percentage of organic sulfur. Pyritic sulfur is oxidized to iron oxide and sulfuric acid which is neutralized by lime.

$$4FeS_2 + 150_2 + 8H_20 \text{----} > 2Fe_20_3 + 8H_2SO_4$$

Unfortunately, due to a cutback in DOE funds in 1980, this project was discontinued. Over 20 different coal were oxydesulfurized at PETC. As mentioned previously, almost all of the pyritic sulfur can be removed by the PETC process, but it has limited success with organic sulfur removal. Table 2 illustrates the reduction in organic sulfur for the 24 coal samples.

Table 2. Organic Sulfur Removal by the PETC Process

No. of Coals	Before		After	
	Range of % S	Ave. & Ave. Dev. % S	Range of % S	Ave. & Ave. Dev. % S
10 coals	0.39 – 0.78	0.61 ± 11	0.36 – 0.79	0.55 ± 0.14
7 coals	0.82 – 1.14	1.07 ± 15	0.76 – 0.84	0.83 ± 0.05
7 coals	1.53 – 2.33	2.05 ± 17	1.22 – 2.03	1.78 ± 0.26

Temperatures were varied in the PETC process from 150° C to one reaction which was run at 250° C. All other reactions were run at 200° or lower. As expected, the oxygen uptake by the coal parallels the heating value loss, and the heating value loss reached a maximum value of 34%. The heating value loss is shown in Table 3, and the reactions are grouped according to the batch temperature. The PETC process does an excellent job of removing the pyritic sulfur, but the organic sulfur removal is hampered by a parallel loss in heating value for the coal.

Table 3. Heating Value Loss in the PETC Process

Temperature	No. of Coal Samples	Percent Heating Loss
150°	9	7.82 ± 4.1
160°	2	3.53 ± 2.7
180°	8	12.7 ± 2.5
200°	4	12.7 ± 1.9
250°	1	18.2

The Ledgemont Oxygen Process

A patent was issued to the Chemical Construction Corp. in 1974 for the desulfurization of coal with air and water (Thomas *et al.* 1974) and a year later Agarval *et al.* (1975) had treated coal with oxygen and water in an attempt to desulfurize the coal. His work was done at the Ledgemont Laboratory of Kennecott Copper Corporation. This Ledgemont oxygen process is similar to the PETC process except they have used oxygen in place of air, and their leaching solution was 0.2 M in Na_2CO_3. The success in removing sulfur with this process is shown in Table 4.

Table 4. Ledgemont Oxygen Leaching Desulfurization Process[a]

Temp	% Pyritic Sulfur Loss	% Organic Sulfur Loss	% Heating Value Loss
200°	56.7%	14.3%	17.4%
220°	70.2%	10.9%	19.2%
240°	54.0%	19.7%	22.6%

[a]Each coal was leached 1h. at 100° with 0.34 MPa 0_2 and 0.2 M Na_2CO_3. A second process at the indicated temperature was done with 0.2 Na_2CO_3 in a nitrogen atmosphere for 1 h.

Again, the greatest success with the Ledgemont process was done with the pyritic sulfur content, and the organic sulfur reduction was at the expense of the heating value of the coal.

Sareen Ammonia — Oxygen Desulfurization

As a modification to the Ledgemont process, Sareen (1977) attempted to remove the sulfur from coal with an ammonia/oxygen/water system. With a reaction time of 2 hours, this process removed 90% of the pyritic sulfur and up to 25% of the organic sulfur.

Sareen's process used an Illinois #6 coal (Total sulfur 4.99%, pyritic sulfur 2.06% and organic sulfur 2.28%) which was ground in a closed-circuit wet ball mill to − 100 mesh. The coal slurry was treated at 130° C in an oxygen-sparged leach reactor at an oxygen pressure of 300 psi.

The chemical equation for the oxidation of pyritic sulfur with an ammonical solution is given below:

$$FeS_2 + 4NH_3 + 7/2\ H_2O + 15/4O_2 \text{-----}> 4NH_4^+ + 2SO_4^= + Fe(OH)_3$$

The sulfide sulfur is converted to soluble sulfate and can be easily removed from the coal matrix via aqueous solutions. Stoichiometrically, the molar ratio of FeS_2/NH_3 is 4, and the experimental runs were always higher than 6.5. The ammonia concentration was varied from 0.5 M to 5.01 M; and the pyritic sulfur removal was found to be independent of the ammonia concentration. However, the organic sulfur removal increased with increase in ammonia concentration from a low of 15% to a high of 23% removal.

No mention was made of the ammonia retention by the coal, but a detailed study of the oxygen consumption was done. Three sources were identified as removing oxygen; 1) oxygen reacting with pyrite 2) oxygen uptake by the coal and 3) oxygen reacting with coal to form carbon dioxide. All three processes were found to be nearly equivalent in oxygen consumption. A fourth area for oxygen consumption could be through the organic sulfur oxidation, but there was no way to measure this oxygen consumption.

The total oxygen consumption by this method, which also allows for a 20% increase for organic sulfur removal, is the same quantity required by the oxygen/water system which is 1000 tons/day of oxygen for a plant size of 8000 tons/day of coal with sulfur content of 4% (50% pyritic and 50% organic sulfur).

A third area Sareen studied was the overall thermal efficiency. Unfortunately the ammonia/oxygen system lost 13% of the thermal efficiency compared to only 8% for the oxygen/water process. They contributed this additional loss to the formation of water soluble carbon acids formed under the basic conditions.

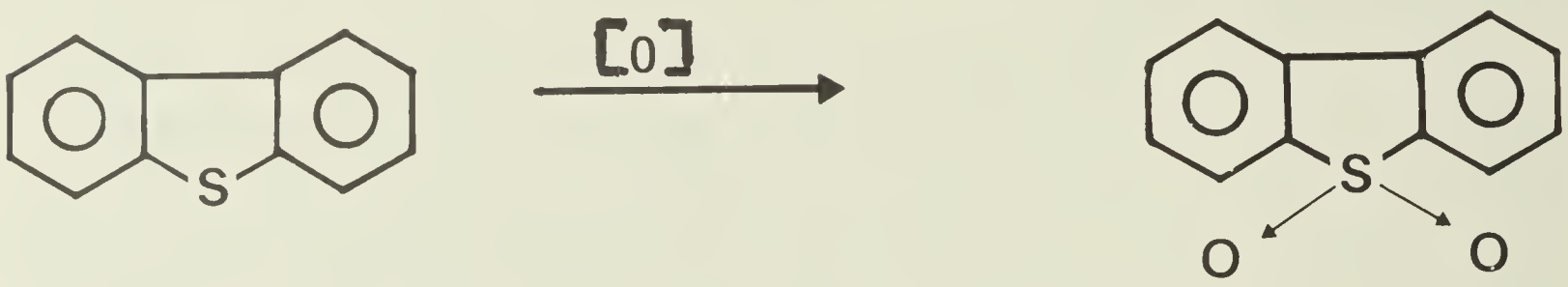
A Table which illustrates the success of this ammonia leaching process as a function of the ammonia concentration is shown below.

Table 5. Pyritic and Organic Sulfur Removal via Air/Ammonia Leaching

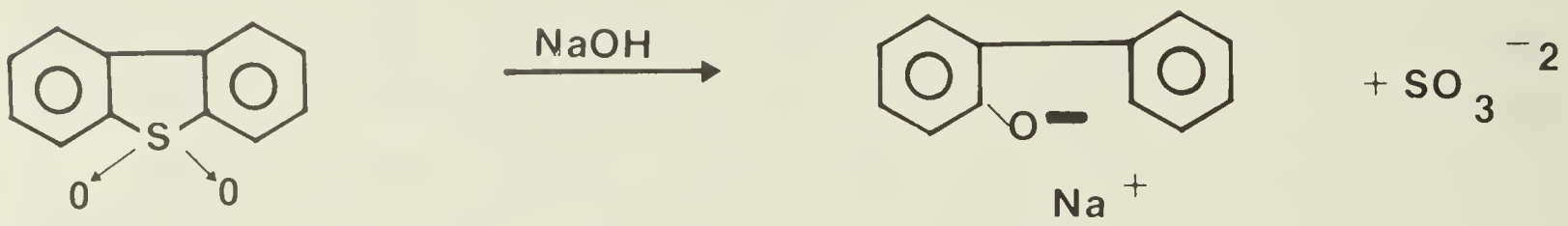
Ammonia Concentration	Reaction Time	Pyritic Sulfur Removal	Organic Sulfur Removal
0.5M	30 min	67%	12%
	120 min	70%	18%
	200 min	82%	30%
1.04M	30 min	48%	17%
	120 min	80%	28%
	200 min	87%	39%
1.94M	30 min	68%	35%
	120 min	86%	—
	200 min	86%	41%
2.95M	30 min	52%	26%
	120 min	81%	35%
	200 min	92%	44%
5.01M	30 min	—	—
	120 min	—	48%
	200 min	—	—

Friedman Air-Nitrogen Dioxide Desulfurization

The most detailed study of oxidative desulfurization of coal was reported by Friedman *et al.* (1977). He attacked the organic sulfur content of coal, specifically, substituted thiophene, with an oxidizing agent which converted the organic sulfide to a sulfone:



Subsequent basic hydrolysis of the sulfone would remove the sulfur as sulfur dioxide:



The oxidative systems they explored in their studies were nitrogen dioxide and air-nitrogen dioxide are known to convert sulfides to sulfone, however, when the coal was treated with nitrogen dioxide, the coal consumed the nitrogen dioxide through the nitration of the coal matrix and, consequently, consumed too much nitrogen dioxide to make this system economically feasible.

The experiments with air were more fruitful, and they were successful in removing 95% of the pyritic sulfur and 40% of the organic sulfur. The pyritic sulfur was removed satisfactorily at temperatures as low as 150° C at reaction times of 1 hr. However, if the air pressure was 200 psi or lower, the reaction is much slower, and improves rapidly above 500 psi.

They reported an upper limit for organic sulfur removal between 40 and 50%. Higher values of organic sulfur can be accomplished with temperatures higher than 200° C, but the heating values of the coal residue is reduced considerably. If the temperature was kept below 200° C, 90% of the heating value could be recovered.

In their oxydesulfurization reaction, no sludge formation was found and the undesirable by-product was the sulfate ion which could be removed as a precipitate with calcium ion ($CaSO_4$). The results of this oxydesulfurization process are shown in the following Table 6.

Ames Oxydesulfurization

Wheelock *et al.* (1983) of Ames Laboratory, have done extensive oxidative experimentation with air and molecular oxygen under acidic and alkaline conditions over the past decade. In their chemical oxydesulfurization process, they have found much better results under alkaline conditions, moreso than under acidic conditions.

The basic conditions used in the Ames' process was 0.2M Na_2CO_3, and both air and oxygen were run at 150° C. Whether air or oxygen were used, the partial pressure of oxygen was always kept at 3.4 atm. Under these conditions the organic sulfur content decreased very little, but pyritic sulfur was decreased over 79%. Reaction times were 1 hr. (See Table 7)

Table 6. Friedman Oxydesulfurization

Temperature	Coal Seam Sample	Pyritic Sulfur Removal	Organic Sulfur Removal
150°	Ill. No. 5	88.9%	—
	Minshall (IN)	95.2%	—
	Lovilia No. 4. (IO)	92.2%	—
	Bevier (KA)	—	20%
	Mammoth (MO)	—	20%
	Wym. No. 9	—	27.3%
160°	Pittsburgh (OH)	92.8%	—
	Lower Freeport (PA)	95.8%	—
180°	Brookville (PA)	96.8%	—
	Pittsburgh (OH)	—	46.7%
	Lower Freeport (PA)	—	20.0%
200°	Ill. No. 6	—	43.4%
	Minshall (IN)	—	20.0%

Table 7. Leaching Coal with Alkali and Air or Oxygen[a]

Coal	Molarity Na_aCO_3	Gas	% Reduction Pyritic Sulfur	% Reduction Organic Sulfur	% Loss Heating Value
Pittsburgh No. 8	0	Air	58%	2%	0.7%
	0.2	Air	77%	7%	4.2%
	0	0_2	58%	0%	0.4%
	0.2	0_2	81%	4%	7.8%
Ill. No. 5	0	Air	67%	+4%[b]	1.1%
	0.2	Air	70%	+7%	8.7%
	0	0_2	67%	+4%	2.1%
	0.2	0_2	74%	+7%	11.7%
Lower Kittanning Coal	0	Air	91%	+116%	1.7%
	0.2	Air	81%	+10%	2.9%
	0	0_2	96%	+110%	0.7%
	0.2	0_2	79%	+5%	2.5%

[a]Reactions were leached for 1 hr at 150° C with 3.4 atm of oxygen partial pressure.
[b](+) indicates an increase in sulfur.

By increasing the partial pressure of oxygen to 6.8 atm, a decrease in organic sulfur of 13% was realized while pyritic sulfur decreased the same as with 3.4 atm of oxygen. Effects of temperature also were studied and maximum sulfur removal occurred between 120° and 150° C for 3.4 atm and 140°-160° C at 13.6 atm oxygen partial pressure. Heating values fell off rapidly with increasing temperatures and higher oxygen partial pressure, and at 200° C the heating value recovery had dropped to 35%.

Wheeler also studied the effects of organic sulfur removal after precleaning the coal. When using precleaned coal, the pyritic sulfur decreased 73% and the organic sulfur increased from 3.60% to 4.04%. In general, the organic sulfur removal increased with increase in oxygen partial pressure, reaction time and temperature, but the heating value loss increased dramatically with an oxygen partial pressure increase.

In summary, with the Ames chemical oxydesulfurization process, high sulfur bituminous coals can be effectively desulfurized with hot dilute alkaline solutions containing dissolved oxygen. Sodium carbonate or bicarbonate solutions at concentrations of 0.2 M to 0.4 M are the most effective. Higher concentrations promote sulfur removal, but at the sacrifice of the heating value loss. At 150° C the optium removal is obtained because at higher temperatures heating value loss is too great. These results are depicted in Table 7.

Desulfurization via Chlorinolysis

Chlorinolysis of coal to promote desulfurization was introduced by the Jet Propulsion Laboratory (JPL) in California in 1977 (Hsu *et al.*, 1977). Their process was a slurry-phase chlorination at ambient temperature of a ground, moist coal in an organic solvent. They attempted to dechlorinate the coal after hydrolyzing the coal at 60°. The dechlorination was done at 350°-550° with steam. Unfortunately, the chlorine content remained too high to make this a feasible process.

Corcoran *et al.* (1983), extended the study of chlorinolysis to different solvents near ambient temperatures and different reaction times. The solvents chosen for their study were water, methanol, carbon tetrachloride and a mixture of methanol and carbon tetrachloride (50/50 vol/vol). As expected, the pyritic sulfur reduction was high, 90% or greater, in most cases. However, the organic sulfur reduction was negligible except for the carbon tetrachloride/methanol mixed solvent where it reached 30.8% reduction for the Ill. No. 6 (hvC). Surprisingly, however, with an Ohio No. 8 (hvA), the reduction of organic sulfur varied from 11.8% to a high of 87% with methanol at 120° C. Unfortunately, the heating value lose and uptake of the chlorine in the coal matrix are two serious disadvantages of this method. (See Table 8)

Table 8. Desulfurization of Coal via Chlorinolysis

Coal	Reaction Temp.	Solvent	Chlorine Uptake	Reduction Pyritic Sulfur	Reduction Organic Sulfur	Heating Value Loss
Ohio No. 8 (hvA)	30°[a]	H_2O	0.396	98%	8.8%	—
	60°[a]	H_2O	0.376	97.5%	0%	—
	80°[a]	H_2O	0.295	95.9%	0%	—
Illinois No. 6 (hvC)	50°[b]	H_2O	0.070	13.4%	11.8%	0.3%
	50°[c]	H_2O	0.216	38.6%	24.6%	+0.9%[e]
	50°[d]	H_2O	0.351	65.9%	31.3%	0.4%
	50°[a]	H_2O	0.396	76.2%	27.4%	4.8%
Ohio No. 8 (hvA)	60°[a]	CCl_4	0.295	95.9%	0%	—
Illinois No. 6 (hvC)	50°[a]	CCl_4	0.413	32.9%	17.1%	+0.7%[e]
Ohio No. 8 (hvA)	50°[a]	CCl_4/MeOH	0.310	98.3%	30.8%	—
Illinois No. 6 (hvC)	50°[a]	CCl_4/MeOH	0.298	85.1%	44.0%	20.1%
Illinois No. 6 (hvC)	50°[a]	H_2O/MeOH	0.348	75.9%	28.9%	+3.2%[e]
Illinois No. 6 (hvC)	50°[a]	MeOH	0.339	87.3%	35.8%	32.8%

[a]- reaction time 120 min.
[b]- reaction time 8 min.
[c]- reaction time 20 min.
[d]- reaction time 45 min.
[e]- increase in heating value

Desulfurization via Bromination

Bromination also has been used by the Ames Laboratory group, (Venier *et al.*, (1984) and they reacted molecular bromine with a well stirred mixture of coal, water and methylene chloride. After collecting the brominated coal and washing it, the coal was fused at 380° C with potassium hydroxide. The percentage of sulfur removal by this method was 94%. If the coal sample was treated with potassium hydroxide before bromination, the desulfurization was only 65% effective. Unfortunately, the coal sample still retained bromine (1 Br/1000C) at the expense of losing hydrogen (approximately 25% hydrogen loss).

Desulfurization via Hydrogen Peroxide

Hydrogen peroxide was used to desulfurize coal, and Taylor *et al.*, (1981) reported limited success with organic sulfur, but complete removal of pyritic sulfur after 100 h. He treated his coal (<200 Tyler mesh) with 30% hydrogen peroxide for up to 16 days at temperatures below 40° C, but could only reduce the organic sulfur content from 2.4% to 2.2%.

Meyers' Ferric Sulfate Desulfurization Process

Milder oxidation methods have been used, and Meyers (1972) used an aqueous solution of ferric sulfate to remove pyritic sulfur. He was successful in removing 90-95% of pyritic sulfur, but little or no organic sulfur was removed.

Meyers initial process investigated 35 major coals with an average total sulfur content of 3.05% and an average pyritic sulfur content of 2.02%. The pyritic sulfur was converted to iron sulfate and elemental sulfur according to the following equation:

$$4.6\ Fe_2(SO_4)_3 + 4.8\ H_2O + FeS_2 \text{-----} > 10.2\ FeSO_4 + 4.8\ H_2SO_4 + 0.8S$$

In this process the iron sulfates are removed by washing the coal, and sulfur is removed by vaporiztion or solvent extraction with toluene, acetone or kerosene. The ferric sulfate leach solution can be regenerated from the ferrous sulfate by oxidizing the aqueous ferrous sulfate with air under acidic conditions.

$$4\ FeSO_4 + 2\ H_2SO_4 + O_2 \text{-----} > 2\ Fe_2(SO_4)_3 + 2\ H_2O$$

Excess sulfates and acids are removed by treating the solution with lime (CaO) to restore the concentration of ferric sulfate to its original concentration for recycling.

Meyers compared his chemical cleaning method to a conventional coal washing process (based on the 1.4 mm, 1.90 float fraction of a float sink analysis). The summary of Meyers results and the conventional float sink method are shown in Table 9.

Table 9. Meyers Chemical Cleaning [$Fe_2(SO_4)_3$] and a Conventional Float Sink Process[a]

No. of	Initial		Meyers Process		Float Sink Process	
Coals	% S(ave)	Range of % S	% S(ave)	Range of % S	% S(ave)	Range of % S
11	1.36%	0.8-1.8%	0.61%	0.4-0.8%	1.11%	0.8-1.7%
9	3.04%	2.0-3.8%	1.15%	0.8-1.7%	2.16%	0.8-3.6%
12	4.92%	4.1-6.6%	1.81%	0.5-2.7%	3.32%	2.0-4.6%

[a]100 g of coal refluxed with 2000 ml of 1 N $Fe_2(SO_4)_3$ solutions from 4 to 6 hrs. Coal was filtered and refluxed an additional 4 to 20 hrs with fresh $Fe_2(SO_4)_3$ solution. Coal was filtered, washed with 0.2 N H_2SO_4 and water washed to remove soluble sulfates. Coal was extracted with 400 ml of toluene to remove sulfur.

For all of these coals treated by the Meyers chemical cleaning process, the average and average deviation for pyritic sulfur removal was 92.4 ± 1.49% while the total sulfur removal was 50.5 ± 9.47%.

Meyers chemical desulfurization process was converted to a process test plant which was built at TRW's Capistrano Test site in California. The plant processed 8-metric tons of coal per day and was operational for several years. However, today no further expansion is planned for the Meyers' process which is contributed mainly to the inability of the process to remove organic sulfur. (Morrison, 1981c)

Desulfurization via Cupric-Ions

Lompa-Krzymien (1982) was successful in removing 100% of the pyritic sulfur as well as the organic sulfur. The oxidizing agent in his reaction was aqueous solutions of cupric ions which oxidize the pyritic sulfur to sulfuric acid as follows:

$$FeS_2 + 14\ CuCl_2 + 8\ H_2O \text{ -----> } 14\ CuCl + FeCl_2 + 2\ H_2SO_4 + 12\ HCl$$

The mechanism for the oxidation of organic sulfur was not investigated, however, Lompa-Krzymien speculated that the sulfur atom was oxidized to sulfoxide or sulfone and carbon-sulfur bonds were cleaved to form sulfuric acid and carbonyl functional groups.

These reactions were carried out at 200° C for 1 hr with 5% or 10% cupric chloride solutions. At 150° C, the success in reaching 100% removal of total sulfur was not accomplished until after 2 days. Unfortunately, no mention was made of the amount of residue that was recovered, consequently, it would not be an effective method of sulfur removal if the recovery of the coal was very poor.

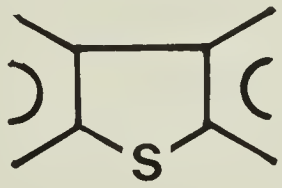
Gravi-Float — Gravi-Melt Process

The Gravi-Float and Gravi-Melt process are oxydesulfurization processes, but are used in conjunction with the Meyers process of desulfurization. (Meyers, 1979) The Gravi-Float process separates the coal into two fractions based on their specific gravity. The process uses a ferric sulfate leach solution (specific gravity 1.3-1.5) to float out a coal fraction that is exceptionally low in pyritic sulfur, ash and metal contaminants. The float fraction still contains the organic sulfur, and must be processed further if the sulfur content is too high.

The Gravi-Melt process is a desulfurization process which removes the organic sulfur content. Consequently, it could be used efficiently with the float fraction from the Gravi-Float separation or with the Meyers' process which has effectively removed the pyritic sulfur.

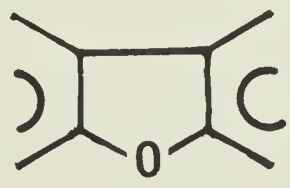
In the Gravi-Melt process the organic sulfur is removed at elevated temperatures with sulfur at atmospheric pressure. The coal is mixed with a dry caustic which impregnates the coal at elevated temperatures to remove the organic sulfur. This process in conjunction with the Gravi-Float process was demonstrated to remove 88% of the sulfur in an Appalachian coal and 92% from a Kentucky coal.

In the Gravi-Melt process the coal is mixed with potassium hydroxide and sodium hydroxide (50/50) at 370° for 1/2 hr. and, subsequently, water washed. (Morrison, 1981c) A suggested reaction pathway for organic sulfur and pyritic sulfur removal is shown below:



coal

$$+\ 2KOH \text{ -----> } K_2S +$$



coal residue

$$8\ FeS_2 + 30\ KOH \text{-----}> 4\ Fe_2O_3 + 14\ K_2S + K_2S_2O_3 + 15\ H_2O$$

Arco Desulfurization Process

The ARCO desulfurization process (A) is similar to the Ledgemont and PETC processes, but is different in the fact that it incorporates a complexing agent for metals, sodium oxalate. The batch tests were run at 120° C for 1 hour at 2.14 atm and the pyritic sulfur removal varied between 88% and 98%. The complexing agent, sodium oxalate, was successful in removing between 78% and 94% of the iron in the five bituminous coals studied.

A second process with a proprietory agent was applied to the coals under more severe conditions after their initial treatment, and 97% to 99% of the pyritic sulfur was removed with 19% - 31% of the organic sulfur removed. Heating value recoveries for the ARCO process were reported to be better than 95% regardless of whether the one step or two step processes were used.

DESULFURIZATION WITH ALKALI METALS AND ALKALI AT ELEVATED TEMPERATURES

Hydrothermal Battelle Process

The hydrothermal treatment of coal by Battelle was begun in 1969 where the ground coal was treated with a caustic solution of 2 to 3% by weight of calcium hydroxide and 10% by weight of sodium hydroxide (Morrison, 1981e). This mixture was heated from 1/6 to 1/2 h. between 250° - 350° C at pressures ranging from 0.79 atm - 3.29 atm. The final treatment was filtration, washing with lime water and drying.

Battelle has adapted this process to continuous flow on a bench scale of 10 kg/h of coal. The continuous flow process was successful in removing 90 to 99% pyritic sulfur and 20 to 70% organic sulfur from several bituminous coals in the Midwestern and Eastern states.

The Battelle process has two distinct advantages in addition to desulfurization, and these are 1) the heating value loss is only 5% to 10% and 2) the trace metals are reduced considerably, e.g. beryllium 70% as a low to potassium 96% as a high.

This hydrothermal process has not gone from bench scale to the pilot plant stage because of the severe corrosion that occurs at elevated temperatures with alkali, and these problems will have to be solved prior to any pilot plant construction.

The success of the Battelle hydrothermal treatment is shown in Table 10 (Slambaugh, 1977)

Desulfurization of Subbituminous Coals with Sodium Hydroxide Solutions.

Droguette *et al.* (1981) made a study of subbituminous coals from LaUnion, Chile. They studied the effects of hydrolysis time, temperature, sodium hydroxide concentration and particle size on the solubilization, ash removal and sulfur reduction. They studied these reactions at two temperatures, 50° C and 80° C with a sodium hydroxide concentration varying from 5 g/dm^3 to 120 g/dm^3. The maximum solubility of the coal occurred at a sodium hydroxide concentration of 50 g/dm^3 where the solubility reached 25.2 wt % at 80° C and only 10.6 wt % for 50° C.

Table 10. Battelle Hydrothermal Process[a]

Coal Seam	S (before)[b]	S (after)[b]
Pittsburgh 8	4.6	0.9
Ohio 6	3.9	1.2
Pittsburgh	3.4	0.7
Upper Freeport	2.4	0.9
Lower Kittanning	2.2	0.9
Lignite	1.5	1.2
Western	1.0	0.3

[a]- laboratory scale
[b]- SO_2 equivalent (lb/mm BTU)

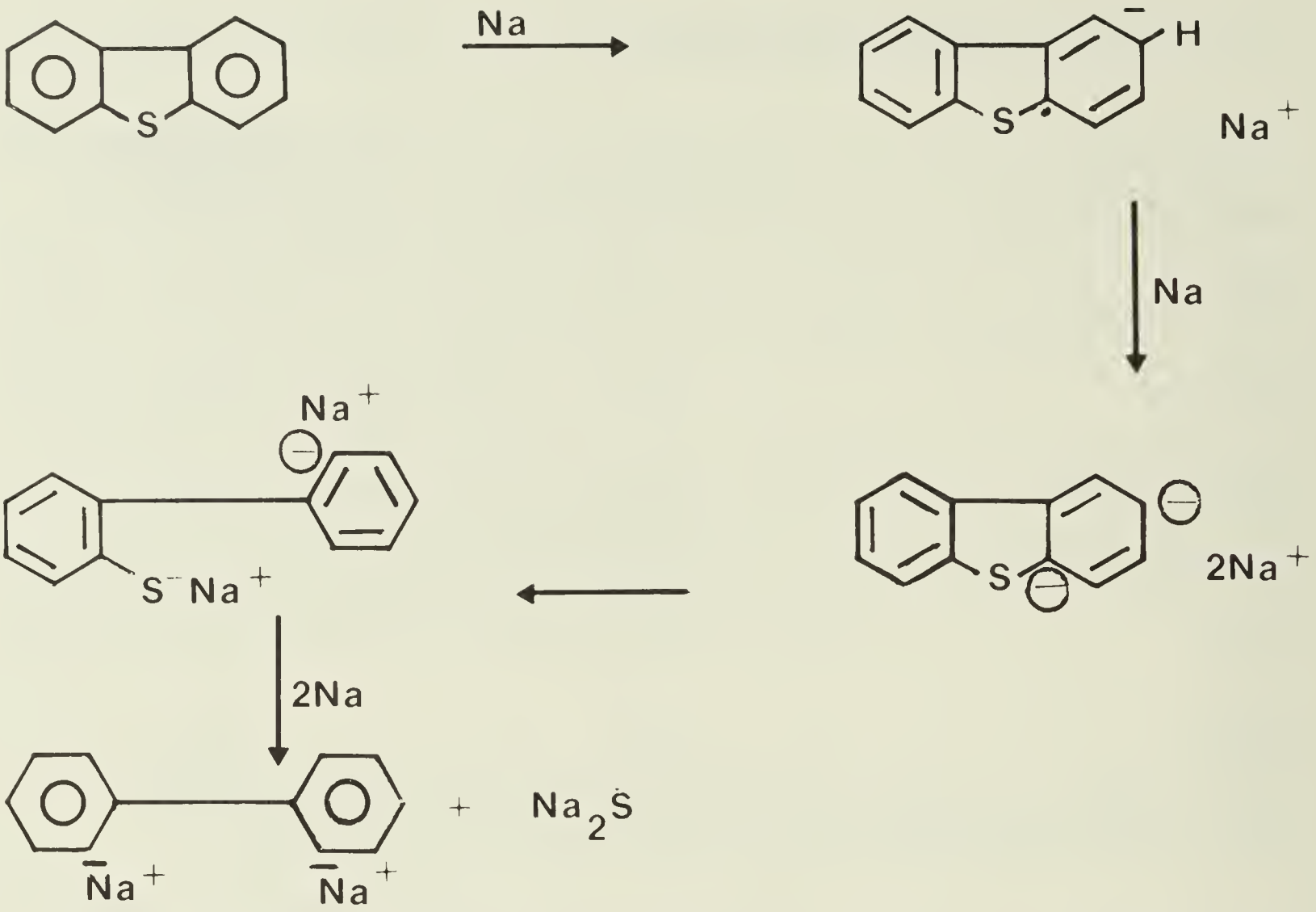
The hydrolysis times for these reactions varied from 1 hr. to 16 hrs., however, the greatest degree of hydrolysis occurred between the first and second hour. Ash content as well as sulfur content was decreased during this time, and their decrease is illustrated in Table 11.

Table 11. Sulfur and Ash Reduction

Temp.	NaOH conc. (g/dm^3)	Decrease % S (wt %)	Decrease Ash (wt %)
50°	5.0	23.8 ± 0.7	2%
50°	100.0	29.8 ± 0.9	3%
80°	5.0	24.6 ± 0.7	22%
80°	100.0	30.7 ± 0.9	28%

Desulfurization of Bituminous and Lignite Coals with Alkali Metals.

Alkali metals will react with organic sulfur compounds to convert the sulfur to sodium sulfide. Sternberg *et al.* (1974) reacted sodium metal with dibenzothiophene in decahydronaphthalene at 350° C under nitrogen, and converted dibenzothiophene to biphenyl, sodium sulfide and an insoluble layer. He explained the reaction with a mechanism patterned after Eisch (1963). The mechanism is illustrated below.



Sternberg did not perform his experiments on coal, but reacted the sodium with petroleum residuum containing 1.65% S. He ran his reactions in a hydrogen atmosphere, but noticed a decrease in sulfur with nitrogen as well. The results of his study are shown in the following Table 12.

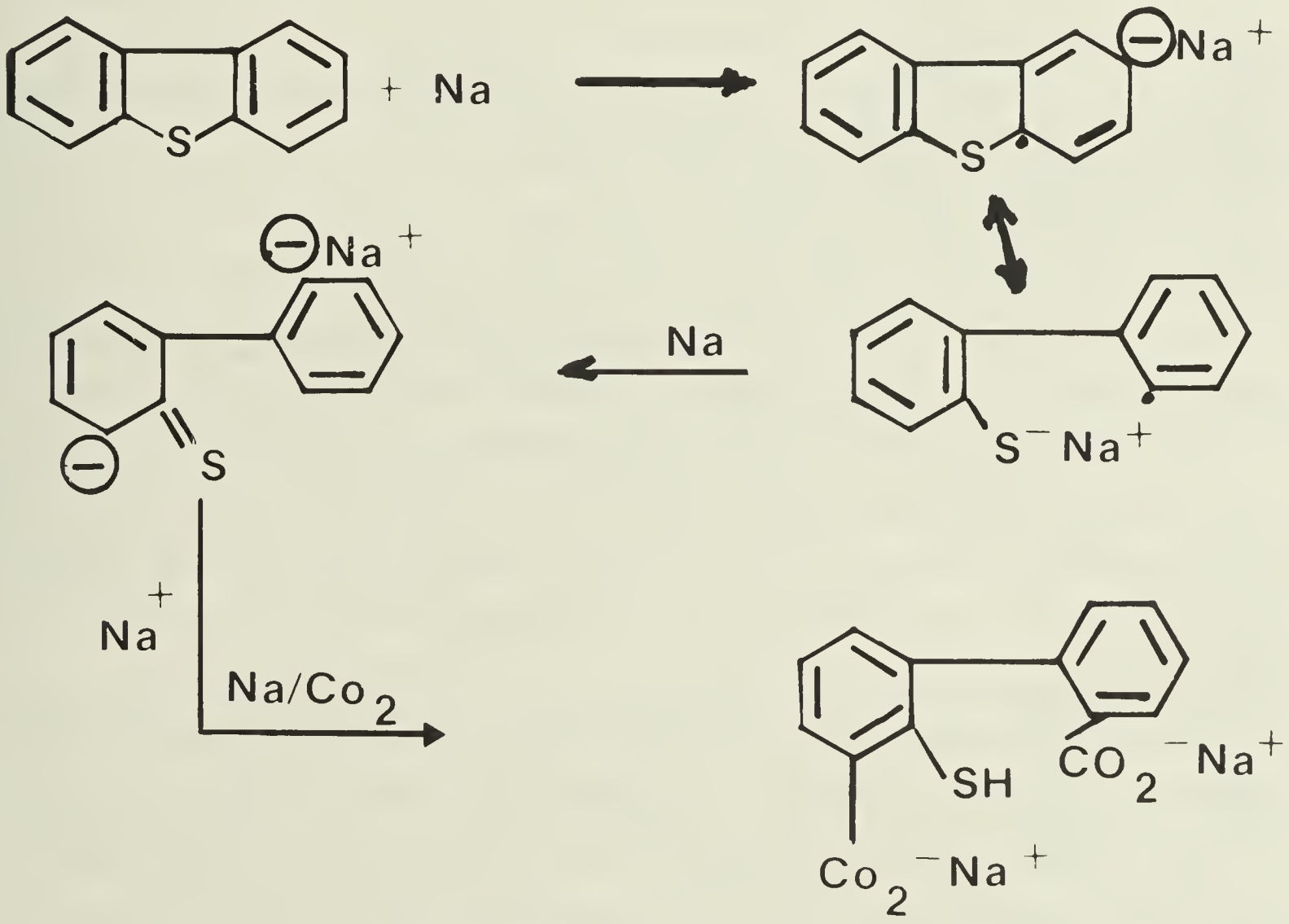
Table 12. Desulfurization of Petroleum Residuum with Sodium Metal[a] Containing 1.65 % S

Sodium per 100 g of Residuum	Na/S Mole Ratio	Gas Pressure (cold) psi	Time hr.	% S Decrease
3.7	3.1	1200	0.5	32%
3.7	3.1	200	0.5	57%
3.7	3.1	200[b]	6	67%
3.7	3.1	200	6	77%
3.7	3.1	200	18	78%
5.7	4.8	200	2	91%
7.1	6.0	200	6	95%
None	—	200	6	13%

[a]Reactions were run at 350° C
[b]All reactions were run with hydrogen except this one which was nitrogen

The weight percent recovery of this residuum was quite high for the eight runs in Table 12, and the average and average deviation for the percent recovery was 92 ± 7.6%. It also is interesting to note that the reaction with no sodium added removed only 13% of the sulfur.

In this laboratory we have been working with alkali metals and their reactions with bituminous and lignite coals. Duty *et al.* (1981) reacted sodium metal with an Illinois bituminous coal in the presence of a carbon dioxide atmosphere in the aprotic solvent tetrahydrofuran. The purpose of adding carbon dioxide was to carboxylate the anionic sites generated by the alkali metal. As suggested previously by Sternberg (1974), sodium will attack polynuclear aromatic sites, and if carbon dioxide is present, this site could be carboxylated to form water soluble acids. Organic sulfur is known to exist in coal as benzo and dibenzothiophene structures, consequently, it would be reasonable to suggest that carbon dioxide could carboxylate these organic sulfur sites as follows.



We studied this reaction from 150° to 350°, and at 350° we ran the reaction with and without the presence of carbon dioxide. The results of these experiments are shown in Table 13 below.

Table 13. Sulfur Reduction with Sodium Metal in Tetrahydrofuran

Temp.	% S Reduction Residue[a]	% S Reduction Residue (dmmf)[b]	% Recovery of Coal
150°	45%	35%	91%
200°	77%	65%	33%[d]
250°	75%	57%	29%[d]
300°	73%	56%	99%
350°	56%	28%	79%
250°	87%	73%	55%

[a]- Residue was material collected from a basic aqueous reflux.
[b]- Demineralization of the residue was done with 1 N HCl.
[c]- This reaction was run with no CO_2.
[d]- These percentages represent an increase in weight gained.

In these reactions 10 g of coal was reacted with 10 g of sodium for 48 hrs. in tetrahydrofuran, the reaction was cooled, vented, and repressurized with carbon dioxide. It was again heated to the reaction temperature for 48 hrs.

The percent reduction in sulfur for the demineralized residues are not as high as the residues because the material that is lost by treating the residues with 1N HCl undoubtedly removes a lot of the sodium atoms and other metals, but very little of the sulfur, e.g. weight is lost in the demineralization step, but little or no sulfur is lost.

If one compares these results with Sternberg's sodium reaction at 350° C (See Table 12) the reduction in sulfur with coal is not as efficient as it is with petroleum residuum. One reason that may account for this is the solubility difference between coal in tetrahydrofuran compared to petroleum residuum in decahydronaphthalene.

Chiri and Duty (1981) also conducted a study with potassium metal with Illinois coal, but the aprotic solvent used in their case was toluene instead of tetrahydrofuran. The experimental conditions were the same with the sodium reactions where 10 g of coal were reacted with 10 g of potassium for 48 hrs and, consequently, reacted with carbon dioxide for 48 hrs. In these reactions with potassium, an electron transfer agent, biphenyl, was added to the toluene solution along with the coal. Hoijtink *et al.* (1956) demonstrated that biphenyl radical would rapidly transfer an electron to the neutral polyaromatic pyrene molecule. Consequently, it was reasonable to assume that biphenyl would transfer the electron readily to the aromatic structure of coal. Unfortunately, the insoluble residue retained some of the biphenyl because 100% recovery was not realized for biphenyl when the residue was refluxed with a mixture of benzene and ether.

The sulfur reduction in these experiments paralleled the sodium metal reactions and are shown in Table 14.

Table 14. Percent Sulfur Reduction in Illinois Coal with Potassium Metal in Toluene

Temp.	% Sulfur Reduction	% Recovery
100°[a]	68%	—
100°	22%	89%
200°	75%	69%
200°	20%	70%
300°	83%	(64%)[b]
300°	91%	(14%)[b]

[a]- This reaction was run in tetrahydrofuran as solvent.
[b]- These represent an increase in the weight of coal recovered.

The increase in weight for 300° reaction can be contributed to two sources; the biphenyl used as the election transfer agent and the toluene becoming incorporated into the coal matrix. Wachowska (1979) reported that anions of the aromatic clusters in coal could react with solvent and electron transfer agents and become incorporated into the reaction products.

The 300° reactions reflect a large decrease in sulfur, however, the decrease is not as large as lower temperatures since the residue weights have increased due to solvent and biphenyl incorporation in the residues.

The potassium metal reactions were run also by Foster and Duty (1983) with a North Dakota lignite that contained 0.89% sulfur. They tried three solvents and varied the conditions as shown in Table 15.

Table 15. Autoclave Reactions

Solvent	Temperature	Gas(es) Employed
Tetrahydrofuran	100° C	N_2 (5 days) CO_2 (5 days)
Naphthalene	200° C	N_2 (5 days) CO_2 (2 days)
Toluene	100° C	CO_2 (5 days)
Toluene	100° C	CO_2 (5 days)
Toluene	100° C	CO_2 (5 days)

Again, the electron transfer agent, biphenyl, was added except for the naphthalene solvent which would act as its own electron-transfer agent. The effectiveness of sulfur removal is shown in Table 16.

Table 16. Sulfur Removal from North Dakota Lignite

Temp.	Solvent	% S Reduction	% Recovery
100°	tetrahydrofuran	68%	42%
200°	naphthalene	63%	32%
100°	toluene	76%	61%
100°	toluene	36%	51%
100°	toluene	46%	55%

Percent recovery is much lower in the case of lignite compared to bituminous coal, but the percent reduction in sulfur is comparable.

Lavin and Duty (1982) also investigated the removal of sulfur from North Dakota lignite at elevated temperatures in the aprotic solvent toluene. They also incorporated biphenyl as the electron transfer agent in all of their reactions. Again, the sulfur reduction was based on the sulfur content of North Dakota lignite (mf) and the recovered residue (dmmf). These results are shown in Table 17.

Table 17. Sulfur Reduction in North Dakota Lignite with Potassium Metal in Toluene[a]

Temp.	% S Reduction	% Recovery
100° C	26%	55%
100° C	89%	58%
200° C	89%	40%
200° C	85%	33%
300° C	84%	82%
300° C	80%	64%

[a]Reactions were run for 5 days under nitrogen, cooled and repressurized under carbon dioxide for 2 days. All reactions were run with 10 g. of coal, 10 g. of potassium and 10 g. of biphenyl.

Again, the percent recovery in these reactions with North Dakota lignite is not very large until the higher temperature is reached (300° C). Unfortunately, the incorporation of solvent and electron transfer agent probably contributes to these high recovery values.

The sulfur reductions are fairly uniform and exceptionally good. Unfortunately, the duplicate run at 100° C does not bear this out, however; where a ridiculously low value of 26% was found.

Desulfurization of Bituminous Coal with Alkali and Carbon Dioxide

Ouchi *et al.* (1978) reported that ethyl alcohol and alkali at elevated temperatures (350°-400° C) solubilized coal (less than 82% C) almost completely in pyridine. He attributed these results to the formation of hydrogen from ethanol at these high temperatures as follows:

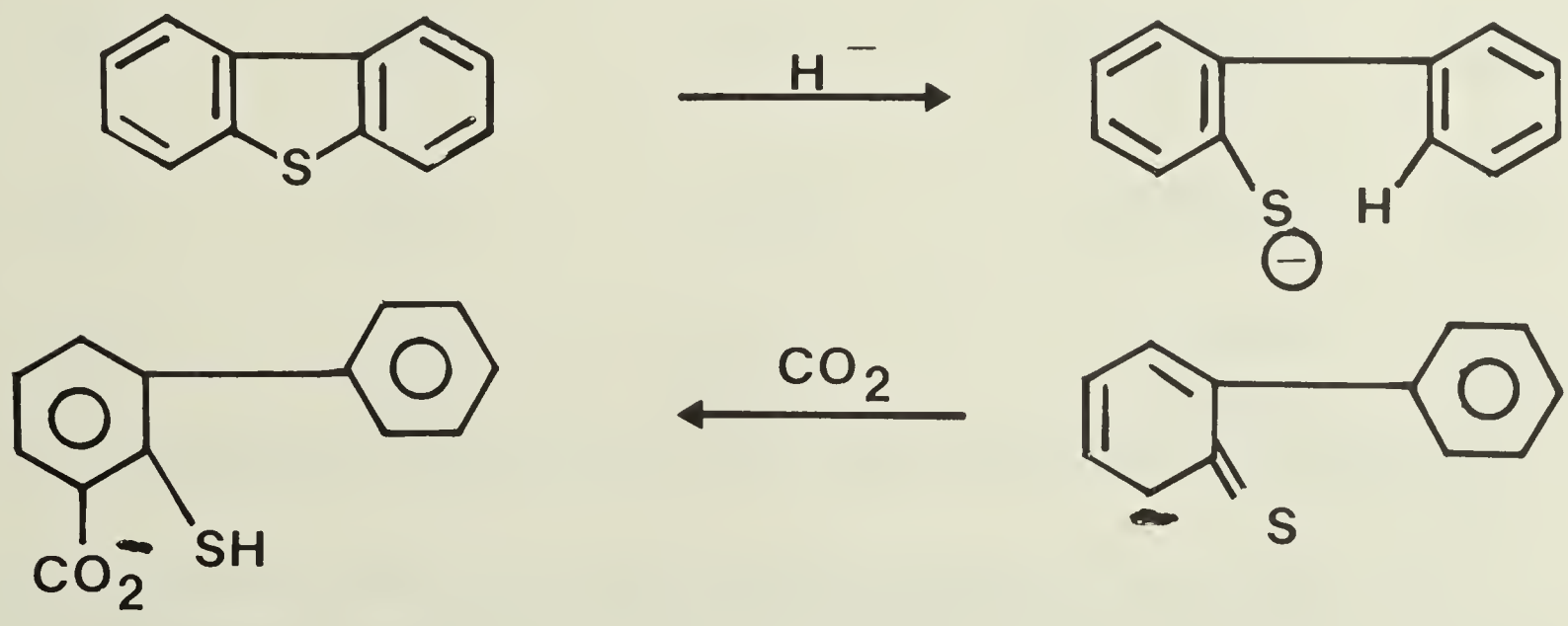
$$CH_3CH_2OH + OH^- \xrightarrow[-H_2O]{} CH_3\overset{O}{\overset{\|}{C}}O^- + 2H$$

Ross *et al.* (1977) had earlier reported the same results with isopropyl alcohol and alkali, and Ouchi (1978) suggested Ross's results could be attributed to the oxidation of isopropyl alcohol with alkali:

$$CH_3\overset{OH}{\overset{|}{C}}HCH_3 \xrightarrow[-H_2O]{OH^-} CH_3-\overset{H}{\overset{|}{\underset{CH_3}{C}}}-O^- \longrightarrow CH_3-\overset{|}{\underset{CH_3}{C}}=O + H^-$$

Ouchi and Makabe (1978) also reported the results of the reaction of methanol with coal and alkali. Their results were similar to ethanol, and the coal was solubilized to 96% and 99% in pyridine with sodium hydroxide and potassium hydroxide, respectively, between 350°-400° C.

With this background information, this laboratory began a study of sulfur removal from Illinois bituminous coal with alkali with protic solvents, ethanol and isopropyl alcohol, and an aprotic solvent triethylamine. The reaction scheme was to react the coal with alkali at different temperatures for 24 hrs, under nitrogen, and then cool and repressurize with carbon dioxide. After pressurizing with carbon dioxide, the temperature again was raised to the reaction temperature for 24 hrs. If Ouchi's supposition was correct, the hydride ion (as well as nascent hydrogen) could initiate the precursors for carboxylation of the coal aromatic structure. This is illustrated as follows for dibenzothiophene.



The preliminary results of this study by Duty *et al.* (1983) was presented at the 39th annual Southwest Regional Meeting of ACS at Tulsa.

After the reaction with carbon dioxide, the solvent was rotary evaporated to remove solvent and the residue was refluxed with 5% (w/w) of potassium hydroxide to remove the carboxylic acids. The residue was demineralized with 1 N HC1, dried and total sulfur was determined. The acids were precipitated from the filtrate with concentrated hydrochloric acid, centrifuged, washed free of chloride ion and dried. The results of these reactions are shown in the following Table 18.

Table 18. Desulfurization of Illinois Bituminous Coal with Alkali and Carbon Dioxide

Temp.	Solvent	Wt. of Acids(g)	% Sulfur[a]	% Recovery (Residue)
100°	Triethylamine	0.12 g	2.37%	90%
100°	Triethylamine	0.09 g	2.06%	89%
100°	2-Propanol	0.13 g	1.36%	94%
100°	2-Propanol	0.20 g	2.42%	88%
100°	Ethanol	0.20 g	2.70%	83%
100°	Ethanol	0.40 g	2.62%	88%
200°	Triethylamine	0.07 g	1.96%	95%
200°	Triethylamine	0.36 g	2.68%	76%
200°	2-Propanol	0.28 g	2.25%	81%
200°	2-Propanol	0.26 g	2.11%	81%
200°	Ethanol	4.7 g	2.17%	84%
200°	Ethanol	3.2 g	2.30%	84%
200°	Triethylamine	0.18 g	1.69%	91%
300°	Triethylamine	0.44 g	1.53%	86%
300°	2-Propanol	0.56 g	1.06%	76%
300°	2-Propanol	0.57 g	1.49%	88%
300°	Ethanol	2.1 g	1.41%	53%
300°	Ethanol	2.7 g	1.45%	67%

[a]Illinois Bituminous #6 coal contained 4.42% sulfur and the dmmf Illinois Bituminous #6 coal contained 3.42% sulfur.

When this project was begun, the goals of the project were to reduce the sulfur content to less than 1% and recover 90% of the coal residue. Our greatest success was accomplished at 300° C with isopropyl alcohol where the percent sulfur was

reduced to 1.06%. Unfortunately, the lowest percent recovery occurred at this temperature with isopropyl alcohol where only 76% recovery was realized.

In the 300° reactions with isopropyl alcohol, the residue contained a highly viscous liquid which presented problems in centrifuging the residue. Consequently, we elected to extract the residue with a benzene/ether (3/1 v/v) reflux prior to extracting the residue with the 5% KOH reflux. The benzene/ether extract produced a neutral fraction which weighed 8.7 g and was predominately aliphatic in nature according to its infrared spectrum (3000-2800 cm^{-1}).

A material balance was determined for the sulfur, and the percent sulfur for each fraction is given in Table 19.

Table 19. Material Balance for Sulfur

Temp.	Solvent	% S Residue	% S Acids	% S Neutral	% S H_2O
300°	2-propanol	18.4%	1.19%	4.32%	76.0%

As was expected, the majority of the sulfur was lost in the water layer, with the smallest amount found in the acids.

The residue was analyzed for pyrite sulfur and organic sulfur for the 300° reaction, and the analyses revealed that the residue contained 1.01% pyritic sulfur and only 0.05% organic sulfur. This analysis was done according to the procedure of Chakrabarti (1978) for pyritic sulfur. The organic sulfur was assumed to be the difference between the total sulfur (1.06%) and the pyritic sulfur.

Since these reactions were all run with carbon dioxide, we elected to determine the BTU/lb value for some of these reactions. Since the carbon dioxide could add to the aromatic structures it seemed reasonable to expect the BTU/lb values to increase for the insoluble coal residues. In Table 20 are found these values for residues from different solvents and temperatures. The bomb calorimeter used was a Parr 1241 adiabatic bomb calorimeter which was standardized with pure benzoic acid which gave an energy equivalent of 2416 ± 1 for three determinations.

Table 20. BTU/lb for Insoluble Coal Residues (dmmf)

Solvent	Rx Temp.	BTU/lb[a]
TEA[b]	100°	11,448 ± 197
TEA	100°	11,616 ± 169
TEA	200°	11,596 ± 148
TEA	200°	12,406 ± 84
TEA	300°	13,167 ± 23
TEA	300°	14,638 ± 951
IPA[b]	100°	11,793 ± 230
IPA	200°	13,092 ± 75
IPA	300°	11,626 ± 48
IPA	300°	9,120 ± 153
Ill. #6 Bituminous Coal (dmmf)		9,891 ± 19

[a]duplicate runs
[b]TEA — triethylamine; IPA — isopropyl alcohol

As expected, the BTU/lb values were all higher than the starting coal except for one run at 300° C. Excluding this 300° value, the average increase over the starting coal was 20.0%.

MISCELLANEOUS PROCESSES FOR DESULFURIZATION OF COAL

Magnetic Process

Magnetic desulfurization of coal is not a new process and was first reported in the literature through a German patent by Siddiqui (1957). A year later Yurovsky *et al.* (1958) reported reductions of sulfur in coal to as high as 85% for pyrite. His process was an air-stream process which increased the magnetic properties of the pyrite. Kester (1965) reported better results without air-stream treatment by pulverizing the coal to a coarse 48/200 mesh fraction and subjecting it to a high-intensity magnetic separation. Since coal is diamagnetic and pyrite is paramagnetic, crushing the coal to liberate the pyrite from the coal matrix should and does prove beneficial for the magnetic separation of pyrite from coal.

Murray (1977) utilized the high extraction magnetic filtration technique for coal which had been used successfully for processing kaoline. His tests were run with coal that would pass through a 200 mesh screen. He ran tests on the solid meshed coal, and also on the 30% solids in water for the wet magnetic tests. For the separations he used Frantz screens with thin sharp ribbons of 430 magnetic stainless steel, and made several passes through these screens that lasted from 30 to 120 seconds. Table 21 shows the reduction achieved by the wet and dry coal samples that were –200 mesh.

Table 21. Desulfurization by Magnetic Filtration

Coal	Total S	Inorganic S	% S Removed	% Inorganic S Removed
IN #5[a]	4.63	2.45	35%	67%
IN #5[b]	4.63	2.47	29%	55%
IN #5[c]	4.63	2.12	18%	25%
IN #6[a]	4.17	0.66	45%	85%
IN #6[b]	4.17	1.14	31%	78%
IN #6[c]	4.17	1.66	31%	39%
IL #5[a]	3.59	2.37	46%	65%
IL #5[b]	3.59	2.41	39%	59%
IL #5[c]	3.59	2.38	20%	30%
IL #6[a]	1.98	1.00	42%	79%
IL #6[b]	1.98	1.03	35%	69%
IL #6[c]	1.98	1.02	21%	40%

[a]Wet coal — three passes
[b]120 — sec retention
[c]dry — three passes

Microwave Process

The microwave treatment of coal was begun in 1977 by the General Electric Company (Morrison, 1977f). The microwave treatment of coal has never gone beyond the bench scale size, and the success of the process has been demonstrated for pyrite as well as for organic sulfur.

Dry powered coal has been subjected to microwave energy for 20 to 60 sec., and the microwave energy heats the pyrite and converts it to a related mineral of pyrite, pyrrhotite. Pyrrhotite has a higher magnetic susceptiblity than pyrite, and can be separated more easily than pyrite with a magnetic separator.

Microwave energy has been used in conjunction with sodium hydroxide to remove both pyrite and organic sulfur. (Morrison, 1981g) The advantage of this process is that the sodium hydroxide and sulfur species can be heated more effectively than the coal itself. Consequently, the pyritic and organic sulfur in coal react with the sodium hydroxide and convert then to soluble sulfides. This process has been successful on a bench scale to remove 90% of the pyritic sulfur and 50 to 70% of the organic sulfur providing the coal is washed and the sodium hydroxide pretreatment and microwave treatment are repeated a second time.

The advantage of the microwave process is that it causes very little coal structure degradation and, consequently, very little heating loss in the coal. Disadvantages would include the sodium retention in the coal and the high cost for microwave energy.

Chemical Comminution Process

Chemical comminution provides a convenient way to crush coal for extensive mineral matter removal. Chemical comminution is accomplished with solvents where methanol and ammonia have found the greatest success. Other solvents such as n-propylamine, pyridine and isopropyl alcohol have been tried (Datta, 1977; Yan, 1984).

Chemicals with a non-bonding electrons have been found to comminuate better, and their method of breakage appears to be along the bedding planes, maceral boundaries. Consequently, the comminution process has its greatest advantage in removing pyrite and ash content of coals. Unfortunately, different coals react differently to chemicals used in chemical comminution, and no process has been found which will work uniformily on all coals.

Yan (1984) discovered that isopropyl alcohol showed synergism with sodium hydroxide in coal comminution with concentrations of less than 0.1 N sodium hydroxide in 90% isopropyl alcohol/water. Very little sodium hydroxide was consumed in this process, and the isopropyl alcohol was recovered quantatively.

Used separately, isopropyl alcohol and sodium hydroxide do not have high levels of comminution, e.g. sodium hydroxide by itself would have to reach 6.2 wt% consumption before it would reach the same level of comminution as with 0.1 N sodium hydroxide and 90% isopropyl alcohol/water system. The consumption of sodium hydroxide was only 2.6 wt% for extensive comminution with isopropyl alcohol.

Yan (1984) found the following trend for solvents as an effective comminution medium.

isopropylalcohol > methyl alcohol >> water

He suggested the reactivity of the hydroxide ion might be enhanced by the solvation of the sodium ion by the isopropyl alcohol or methanol.

SUMMARY

Coal desulfurization has come a long way in the past 15 years, and chemical desulfurization has been at the fore-front of this progression. Unfortunately, unless some new technique is developed, the chemical desulfurization processes appears to be at a stalemate. A proliferous number of chemicals has been tried, and their greatest success has been in removing the inorganic sulfur, but their success with organic sulfur has been minimal.

Organic sulfur is incorporated into the carbon structure of the coal molecules, and as the present processes have shown, to remove the sulfur from the carbon structures, success is achieved at the heating value loss of the coal.

Chemical comminution is an interesting phenonunium, but it greatest success, also, has been in removing the pyritic sulfur which is not chemically bound to the coal structure as the organic sulfur atoms are. Microwave treatment and magnetic desulfurization have demonstrated, also, success with pyritic sulfur and limited success with the organic sulfur.

At the present time, desulfurization can be accomplished whereby the pyritic sulfur can be almost completely removed with several processes; Meyers ferric sulfate process, Ames air oxidation process under alkaline conditions, and the Arco complexing agents for metals to name a few. Unfortunately, a process has not been developed which successfully removes the organic sulfur from coal, consequently, to successfully remove the total sulfur from a coal burning establishment, a chemical desulfurization process would have to be the precursor to a stack gas scrubbing process as the final stage in removing sulfur.

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POWER PLANT EMISSIONS AND CANCER MORTALITY RATES

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ABSTRACT

Atmospheric emissions from coal-fired electrical generating stations contain several carcinogens, as well as other non-carcinogenic substances such as SO_2. In areas where the main sources of SO_2 are coal-fired generating stations, the SO_2 may be used as an indicator of general air pollution levels from these plants. Coal-fired power plants are the main source of atmospheric SO_2 in Ohio. Significant associations were found between county Cancer and Respiratory Cancer mortality rates and estimated annual SO_2 emissions in Ohio. Linear regression demonstrated that the associations were of considerable magnitude. Living near a conventional coal-fired power plant, therefore may be a cancer risk factor.

INTRODUCTION

Sulfur dioxide levels can be utilized as an indicator for the general degree of atmospheric pollution (National Air Pollution Control Association, 1969; Wark and Warner, 1976). Where SO_2 levels are high, it can be reasonably expected that other pulmonary irritants, e.g., particulates, are also present in large concentrations.

A study was undertaken, using SO_2 emissions estimates from coal-fired power plants as a surrogate for air pollution levels, to ascertain whether any relationships exist between pollution levels and chronic disease mortality rates in the state of Ohio. Specifically, the study examined disease-specific mortality rates in Ohio counties with coal-fired power plants and counties without such installations in order to determine whether or not these two groups of mortality rates differed.

METHODOLOGY

Ohio was selected for investigation because steam-electric power plants are responsible for at least 70% of all SO_2 emissions in that state (Park, 1974). Twenty-

seven Ohio counties served as the sample. Twenty counties contained at least one coal-fired power plant whose installed generating capacity exceeded 50 megawatts electricity. Seven counties had no such power plants. In total, the sample accounted for 29 of the 49 Ohio power plants operating for at least five years prior to 1974.

Mortality data were derived from *Vital Statistics of the United States* for the years 1971-1974. Rates were age-adjusted to the 1974 (mid-year) population of Ohio. Disease categories were selected based on reviews by Lave and Seskin (1970) and Goldsmith (1974). The categories employed were: 1) Cancer (140-209); 2) Respiratory Cancer (160-163); 3) Major Cardiovascular Diseases (390-448); and 4) Bronchitis-Emphysema-Asthma (490-493).

Sulfur dioxide emissions were estimated from power plant data issued by the Federal Power Commission. Estimates were based on an emissions factor of approximately 3.4 kg (7.4 lbs.) of SO_2 produced by the burning of one ton of coal in Ohio power plants (Park, 1974). No data were located for counties without power plants, so it was assumed that SO_2 emissions in these counties were very much less than the emissions in power plant counties.

On the surface, there exists one potential problem encountered in the use of SO_2 stack emissions in this study. The behavior of plumes, e.g., dispersal distance, has not been considered. While it is possible that emissions from tall stacks could be carried out of the county of origin by air movements, the dilution factor $\frac{\chi}{q}$ is so great that most of the noxious agents originally in the plume will reach the ground relatively close to the point of origin. Therefore, it is believed that stack emissions can serve as surrogates for general air pollution contributions from coal fired generating plants.

Statistical analysis commenced with two-sample t-tests to determine whether differences in disease-specific mortality rates existed between the power plant counties and those without power plants. Next, Pearson product-moment correlation coefficients were computed to determine associations between SO_2 emissions and mortality rates. While correlation provides an adequate initial measurement of association, the correlation coefficient provides no indication of the magnitude of an effect. Therefore, regression was performed on statistically significant associations.

ANALYSIS AND DISCUSSION

Table 1 presents the results of two-sample t-tests. The null hypothesis postulates that for each disease category no difference existed between the mean rates of the power plant counties and the non-power plant counties. The null was rejected in the cases of cancer and respiratory cancer, indicating that Ohio's power plant counties have, on the average, significantly higher death rates for these diseases than do counties without power plants. It might be argued that the power plant counties are more urbanized and that this is merely an "urban effect"; however, eight of the power plant counties have populations that are less than 50% urban.

Table 2 lists the correlation coefficients between disease mortality rates and SO_2 emissions. Estimated SO_2 emissions were moderately associated with both cancer and respiratory cancer mortality rates ($r = .546$ and .491, respectively). Unlike other studies, no associations were found between SO_2 emissions and Major Cardiovascular Diseases or the category Bronchitis-Emphysema-Asthma.

Regression equations were developed for the two statistically significant associations to determine the magnitude of the effects SO_2 emissions had on the cancer variables:

$$\text{Cancer Mortality Rate} = 122.4 + 21.5\ (\log_{10} SO_2)$$

$$\text{Respiratory Cancer Mortality Rate} = 24.2 + 6.0\ (\log_{10} SO_2)$$

These equations showed that as SO_2 emissions rise by a factor of 10, the cancer mortality rate increases by more than 14% (e.g., from 155 to 177 per 100,000 per year) and the respiratory cancer mortality rate increases by 16% (e.g., from 37.5 to 43.5 per 100,000 per year). It should be emphasized here that there is no evidence that the air-borne oxides of sulfur are carcinogenic and that the SO_2 emissions are used here only as a general measure of air pollution from power plants. However, since the emissions from coal-fired power plants are known to include carcinogens such as polyaromatic hydrocarbons and naturally occurring long-lived radioactivity, these findings are consistant with studies finding associations between air pollution and various cancers (Hagstrom et al., 1967; Winkelstein and Kantor, 1969).

It was thought that large urban centers in certain counties might have presented problems of colinearity, so another set of correlation coefficients was computed, omitting highly urbanized counties. The associations were similar (Cancer and SO_2, $r = .588$; Respiratory Cancer and SO_2, $r = .507$), thus showing that urbanization was not a confounding factor.

CONCLUSIONS

Statistical associations were found between power plant annual SO_2 emissions in Ohio and county mortality rates for Cancer (140-209) and Respiratory Cancer (160-163). No similar relationships were found for Major Cardiovascular Diseases (390-448) or Bronchitis-Emphysema-Asthma (490-493). There was a significant difference in cancer and respiratory cancer mortality rates between coal-fired power plant counties and counties without coal-fired power plants.

While SO_2 itself is not carcinogenic, power plant emissions contain various carcinogens. Information presented here suggests that SO_2 levels might serve well as indicators of general pollution. In areas where coal-fired power plants are the single greatest source of SO_2, emissions estimates from power plant data may be excellent surrogates for general air pollution. Since coal-fired power plants are the main source of most SO_2 emissions and because power plant plumes contain various carcinogens, further research should be undertaken on the local level to examine the degree to which living near a coal-fired power plant is a cancer risk factor.

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Table 1. Mortality rate differences between counties with and without power plants.

CANCER	N	Mean*	± S.D.
Power plant counties	20	177.7	27.8
No power plant counties	7	127.2	25.5
t = 4.233 (significant at α = .05)			
RESPIRATORY CANCER	N	Mean	SD
Power plant counties	20	39.1	8.7
No power plant counties	7	25.2	8.4
t = 3.729 (significant at α = .05)			
MAJOR CARDIOVASCULAR**	N	Mean	SD
Power plant counties	20	491.6	31.7
No power plant counties	7	492.0	42.0
t = .023 (not significant)			
BRONCHITIS***	N	Mean	SD
Power plant counties	20	2.7	.03
No power plant counties	7	2.7	.04
t = .010 (not significant)			

*Mean age-adjusted death rate
**Major Cardiovascular Diseases
***Bronchitis-Emphysema-Asthma

Table 2. Correlation coefficients between log of SO_2 emissions* and disease incidence.

Disease Variable	Correlation Coefficient
Cancer	.546**
Respiratory Cancer	.491**
Major Cardiovascular Disease	.127***
Bronchitis-Emphysema-Asthma	.212***

*$\log_{10}$ of estimated annual power plant SO_2 emissions (tons/year)
**significant at $p < .05$
***not significant

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FOREST TYPES AT FOX RIDGE STATE PARK, COLES COUNTY, ILLINOIS

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ABSTRACT

The woody overstory of five forest types were surveyed at Fox Ridge State Park, Coles County, Illinois. These included an upland forest (330 stems per ha, basal area of 23.62 sq m per ha), a north-facing hillside forest (407 stems per ha, basal area of 20.19 sq m per ha), a south-facing hillside forest (315 stems per ha, basal area of 21.41 sq m per ha), a terrace forest (433 stems per ha, basal area of 23.00 sq m per ha), and a floodplain forest (616 stems per ha, basal area of 39.62 sq m per ha).

INTRODUCTION

Fox Ridge State Park is located about 8 miles south of Charleston, Coles County, Illinois on the bluffs of the Embarass River, and on the southern edge of the Shelbyville Moraine, the terminal moraine of Wisconsin glaciation. The park is 865 acres in size with the elevation varying from 540 feet to 720 feet above sea level. Leading back from the river bluffs are several deep, relatively narrow valleys. The amount of bottomland in these valleyss is fairly limited, though one valley has been dammed to form an 18 acre lake (Mohlenbrock, 1976). Between these valleys are flat, narrow ridges. Originally the entire area was probably forested since upland and terrace forest soils are the only soil types reported for the area (Smith et al., 1929). Early settlers cleared the relatively flat uplands and bottomlands, but much of the park escaped being clear cut because of its rough topography. The slopes did suffer some cutting in the past, however, and prior to being dedicated as a state park in 1939, most of the area was probably grazed. The present study was undertaken to determine the floristic composition of the forest types that presently exist in the park.

MATERIALS AND METHODS

The forest areas surveyed vary from one to two hecatres in size, and represent the best quality example of each forest type found in the park. Each area was divided

into quadrats 25 m on a side (0.154 acres), and the number, size, and species above 10 cm d.b.h. were recorded for each quadrat. All living and dead-standing trees were identified and measured to the nearest cm. The importance value (IV) was then calculated for each species in each of the forests sampled. As used here, the IV determination follows the procedure developed by McIntosh (1957), and later Boggess (1964), in which the IV is the sum of the relative frequency, relative density, and relative dominance. The nomenclature used follows Mohlenbrock (1975).

RESULTS AND DISCUSSION

A total of five forest areas were studied, an upland forest (Table 1), a north-facing hillside forest (Table 2), a south-facing hillside forest (Table 3), a terrace forest (Table 4), and a floodplain forest. The tree species encountered in each forest area with their relative values, average diameters, and the number of individuals per hectare in broad diameter classes are included in the tables.

Upland Forest: — This forest type occurs on the ridges and gentle slopes throughout much of the park. Most of these areas were probably heavily logged before the area was dedicated as a state park in 1939. During the present study a 1 hectare section of the best quality representative of this forest type was surveyed. In this area the arborescent species encountered average 330 stems per ha with a basal area of 23.62 sq m per ha (Table 1). The dominant overstory species is white oak with an IV of 78.1 (out of a possible 300), followed by black oak (IV of 50.0), and sugar maple (IV of 35.6). White oak is well represented in all diameter classes, and has an average diameter of 33 cm, indicating its continued importance in the woodlot. Black oak, in contrast, has relatively poor size class distribution, being relatively common in the 2-5 dm diameter classes. Most of the remaining species are well represented in the lower diameter classes, and except for sugar maple, rarely exceed the 3-4 dm diameter class. The large number of sugar maple, white ash, and basswood in the 1-2 dm diameter class indicates that these species will increase in importance in the forest.

North-facing Hillside Forest: — This mesic forest is located on the south side of Ridge Lake, and during the present survey a 1.4 ha section was studied. In this area the arborescent species average 407 stems per ha with a basal area of 20.19 sq m per ha (Table 2). Red oak (IV of 86.4), sugar maple (IV of 58.0), and white oak (IV of 44.8) are by far the dominant species. All have fairly good size class distribution indicating their continued importance in the woods. Of these species, sugar maple will probably increase more rapidly, however, due to the large number of individuals in the 1-2 dm diameter class, and because of its high gap phase replacement potential. Other mesic species that will probably increase in importance are basswood and yellow chestnut oak, while hop hornbeam and flowering dogwood will continue as important understory species. Understory trees and shrubs are much more common in this woods than in the other upland forests studied.

South-facing Hillside Forest: — This forest type is located on a relatively steep south-facing hillside, and is slightly drier than the other upland forests in the park. The area surveyed is 1 ha in size, and the tree species average 315 stems per ha with a basal area of 21.41 sq m per ha (Table 3). White oak is by far the leading dominant, accounting for a third of the entire importance value. It is well represented in all diameter classes, and accounts for about half of the basal area in the woods.

Sugar maple (IV of 75.2) and red oak (IV of 31.4) account for another third of the importance value. All three species are well represented in the lower diameter classes, and as a result will continue as important dominants. Though present, the hickories (shagbark and mockernut) are not extremely common in the woods, and have relatively low importance values. Most of the remaining species are present only in the lower diameter classes. This forest type is extremely common throughout the park, occurring on many of the south-, east-, and west-facing slopes, as well as in many of the steep valleys to the north of Ridge Lake.

Terrace Forest: — This forest type is located along both sides of a small stream near the south edge of the park. It has the highest woody species diversity of the areas studied with 21 woody taxa (Table 4). In this lowland wet mesic forest, of which a 1.2 ha section was surveyed, the arborescent species average 433 stems per ha with a basal area of 23 sq m per ha. Sycamore (IV of 44.9) is the leading dominant followed by buckeye (IV of 32.1), hackberry (IV 31.9), sugar maple (IV of 31.5), and box elder (IV of 28.9). All other species have an IV of less than 18. Except for sycamore, all of the taxa have good size class distribution, and their importance in the woods should increase. Sycamore, in contrast, is well represented only in the higher diameter classes, and its importance will probably decrease as the veteran trees die. Numerous understory trees and shrub are an important feature of this forest type, with blue beech and redbud being extremely common in the 1-2 dm diameter class.

Floodplain Forest: — The floodplain forest in the park was studied by Crites and Ebinger (1969). This wet floodplain, in which prolonged flooding has lowered species diversity, is dominated by cottonwood (IV of 101.1), followed by box elder (IV of 74.1) and silver maple (IV of 62.9). Other woody taxa encountered include black willow, slippery elm, sycamore, white ash, hackberry, black walnut, and buckeye. In this forest the arborescent taxa average 616 stems per ha with a basal area of 39.62 sq m per ha.

Though the forests in the park were heavily disturbed prior to 1939, they have recovered fairly well. Most, however, still show some indication of past disturbance particularly in tree size, the extent of coppice growth, and in the presence of introduced and successional tree species.

In general, the forests of the park are similar to other woods associated with the Shelbyville moraine that have been heavily utilized by man. The upland and hillside forests are very similar to a coppice forest studied by Ebinger (1973) which is also located on the moraine in Coles County, Illinois. Also, the terrace forest is similar in species composition to a low terrace forest located in Clark County, Illinois (Nyboer and Ebinger, 1976), while the floodplain forest is similar to other floodplain forests located along the Embarass River (Crites and Ebinger, 1969), and the Wabash River (Phillippe and Ebinger, 1973).

One disturbing feature of the forests in the park is the large number of sugar maples found. This shade tolerant species, which is well represented in the lower diameter classes, and has a high gap phase replacement potential, will undoubtedly increase in importance. This will result in a shift from the oak-hickory forests that previously occurred in the area to one in which sugar maple will become a leading dominant. Similar results have been observed in Baber Woods, a morainial forest in Edgar County, Illinois, by McClain and Ebinger (1968). It is very possible that the lack of ground fires during the present century is responsible for this change.

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Table 1. Number of trees and basal area per hectare, diameter classes, relative values, and average diameters for the leading dominants in an upland forest at Fox Ridge State Park, Coles County, Illinois.

Species	Number of trees per hectare By Diameter Classes (dm) 1-2	2-3	3-4	4-5	5-6	6+	Density (trees/ha)	Basal Area (m^2/ha)	Relative Values Rel. Freq.	Rel. Den.	Rel. Dom.	I.V.	Av. Diam. (cm)
Quercus alba L.	16	26	26	12	10	2	92	8.91	12.5	27.9	37.7	78.1	33
Quercus velutina Lam.	2	10	22	10	2	2	48	5.44	12.5	14.5	23.0	50.0	37
Acer saccharum Marsh.	14	—	—	14	2	2	32	3.55	10.9	9.7	15.0	35.6	33
Fraxinus americana L.	16	18	—	—	—	—	34	1.21	10.9	10.3	5.1	26.3	20
Tilia americana L.	14	10	6	—	—	—	30	1.16	9.4	9.1	4.9	23.4	21
Quercus rubra L.	6	4	8	—	—	—	18	.97	9.4	5.5	4.1	19.0	25
Sassafras albidum (Nutt.) Nees.	28	—	—	—	—	—	28	.37	7.8	8.5	1.6	17.9	13
Ulmus rubra Muhl.	4	4	4	—	—	—	12	.57	6.3	3.6	2.4	12.3	23
Others (9 species)	18	12	4	2	—	—	36	1.44	20.3	10.9	6.2	37.4	
Totals	118	84	70	38	14	6	330	23.62	100.0	100.0	100.0	300.0	

Table 2. Number of trees and basal area per hectare, diameter classes, relative values, and average diameters for the leading dominants on a north-facing hillside at Fox Ridge State Park, Coles County, Illinois.

Species	Number of trees per hectare By Diameter Classes (dm) 1-2	2-3	3-4	4-5	5-6	6+	Density (trees/ha)	Basal Area (m^2/ha)	Relative Values Rel. Freq.	Rel. Den.	Rel. Dom.	I.V.	Av. Diam. (cm)
Quercus rubra L.	23	42	23	17	7	—	112	8.95	14.4	27.7	44.3	86.4	29
Acer saccharum Marsh.	67	30	7	1	—	1	106	3.41	15.1	26.0	16.9	58.0	19
Quercus alba L.	29	16	11	4	—	1	61	3.68	11.6	15.0	18.2	44.8	24
Ostrya virginiana (Mill.) K. Koch.	42	—	—	—	—	—	42	.51	13.7	10.3	2.5	26.5	12
Carya ovata (Mill.) K. Koch.	11	5	5	—	1	—	22	1.13	8.9	5.4	5.6	19.9	23
Tilia americana L.	11	7	2	—	—	—	20	.73	8.2	4.9	3.6	16.7	20
Carya tomentosa (Poir.) Nutt.	7	4	1	—	—	—	12	.44	6.2	2.9	2.2	11.3	20
Querus muhlenbergii Engelm.	5	2	3	—	—	—	10	.48	6.2	2.5	2.4	11.1	22
Fraxinus americana L.	1	—	1	1	—	—	3	.30	2.1	.7	1.5	4.3	29
Fraxinus quadrangulata Michx.	1	1	1	—	—	—	3	.16	2.1	.7	.8	3.6	21
Cornus florida L.	5	—	—	—	—	—	5	.06	2.1	1.2	.3	3.6	12
Others (9 species)	9	1	1	—	—	—	11	.34	9.4	2.7	1.7	13.8	
Totals	211	108	55	23	8	2	407	20.19	100.0	100.0	100.0	300.0	

Table 3. Number of trees and basal area per hectare, diameter classes, relative values, and average diameters for the leading dominants on a south-facing hillside at Fox Ridge State Park, Coles County, Illinois.

Species	Number of trees per hectare By Diameter Classes (dm) 1-2	2-3	3-4	4-5	5-6	6+	Density (trees/ha)	Basal Area (m^2/ha)	Relative Values Rel. Freq.	Rel. Den.	Rel. Dom.	I.V.	Av. Diam. (cm)
Quercus alba L.	22	29	28	22	4	4	109	10.19	17.8	34.6	47.6	100.0	32
Acer saccharum Marsh.	39	35	17	6	3	—	100	5.86	16.1	31.7	27.4	75.2	25
Quercus rubra L.	17	4	7	2	2	—	32	1.79	12.9	10.2	8.3	31.4	24
Quercus velutina Lam.	4	6	4	—	—	—	14	.82	9.7	4.4	3.8	17.9	26
Carya ovata (Mill.) K. Koch.	4	7	4	—	—	—	15	.90	8.1	4.8	4.2	17.1	25
Carya tomentosa (Poir.) Nutt.	4	4	2	—	—	—	10	.48	8.1	3.2	2.3	13.6	23
Sassafras albidum (Nutt.) Nees.	10	—	—	—	—	—	10	.11	8.1	3.2	.5	11.8	12
Querus muhlenbergii Engelm.	—	—	2	3	—	—	5	.52	4.8	1.6	2.4	8.8	39
Fraxinus americana L.	4	4	—	—	—	—	8	.28	4.8	2.5	1.3	8.6	20
Ulmus rubra Muhl.	2	3	—	—	—	—	5	.21	3.2	1.6	1.0	5.8	24
Others (3 species)	3	2	2	—	—	—	7	.25	6.4	2.2	1.2	9.8	
Totals	109	94	66	33	9	4	315	21.41	100.0	100.0	100.0	300.0	

Table 4. Number of trees and basal area per hectare, diameter classes, relative values, and average diameters for the leading dominants in a terrace forest at Fox Ridge State Park, Coles County, Illinois.

Species	Number of trees per hectare By Diameter Classes (dm) 1-2	2-3	3-4	4-5	5-6	6+	Density (trees/ha)	Basal Area (m^2/ha)	Relative Values Rel. Freq.	Rel. Den.	Rel. Dom.	I.V.	Av. Diam. (cm)
Platanus occidentalis L.	5	8	15	14	1	4	47	6.09	7.8	10.9	26.2	44.9	39
Aesculus glabra Willd.	42	14	6	2	—	—	64	1.95	8.8	14.9	8.4	32.1	18
Celtis occidentalis L.	22	17	8	2	2	—	51	2.64	8.8	11.8	11.3	31.9	24
Acer saccharum Marsh.	35	10	4	1	2	—	52	2.13	10.4	12.0	9.1	31.5	20
Acer negundo L.	34	17	3	1	—	—	55	1.85	8.3	12.7	7.9	28.9	20
Tilia americana L.	12	6	6	1	1	—	26	1.33	5.7	6.0	5.7	17.4	23
Ulmus americana L.	12	3	2	1	—	—	18	.57	7.3	4.2	2.4	13.9	18
Juglans nigra L.	2	5	2	3	—	1	13	1.24	4.7	3.0	5.3	13.0	33
Ulmus rubra Muhl.	3	6	3	1	—	—	13	.77	5.2	3.0	3.3	11.5	26
Quercus macrocarpa Michx.	6	1	2	1	—	2	12	1.08	4.1	2.8	4.6	11.5	29
Carya cordiformis (Wang.) K. Koch.	6	3	3	1	—	—	13	.76	4.7	3.0	3.3	11.0	25
Carpinus caroliniana Walt.	18	—	—	—	—	—	18	.21	5.7	4.2	.9	10.8	12
Quercus muhlenbergii Englem.	6	1	2	1	—	—	10	.42	4.1	2.3	1.8	8.2	21
Fraxinus pennsylvanica Marsh.	3	2	2	—	—	1	8	.75	3.1	1.8	3.2	8.1	28
Cercis canadensis L.	11	—	—	—	—	—	11	.16	4.1	2.5	.8	7.4	13
Others (6 species)	9	6	5	2	—	—	22	1.35	7.2	4.9	5.8	17.9	
Totals	226	99	63	31	6	8	433	23.30	100.0	100.0	100.0	300.0	

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MOVEMENTS AND HABITAT SELECTION OF INTRODUCED ADULT LARGEMOUTH BASS (*MICROPTERUS SALMOIDES*) IN AN ILLINOIS LAKE

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ABSTRACT

The movements, home areas, and habitat selection of introduced adult largemouth bass (*Micropterus salmoides*) released in an Illinois lake were studied by radiotelemetry. The fish moved from their release sites along the edge of a macrophyte patch, and then remained in one location for a short time period (2-13 days). Thereafter, they swam around the lake or moved to another location where they remained for a few days. Average daily movements of individual fish, excluding those within home areas, ranged from 129 to 324 m. Maximum distances for each fish varied from 290 m to 680 m. The sizes of home areas varied from 0.01 to 3.15 hectares. Often, two or more radio-tracked fish occurred in the same home area or were swimming around the lake together. All of the introduced largemouth basss were usually located (51% to 59% of a tracking day) in an ecotone, i.e., edge of macrophyte patch. Heavy macrophyte patches were also heavily utilized. Habitat selection for ecotones was significantly greater ($p < 0.05$) than that for any other habitat. Habitat selection for heavy macrophytes was second to that of ecotones and significantly different ($p < 0.05$) from other habitats. Whether fish were located in an ecotone or macrophyte patch, they were usually found around or in a small patch of broadleafed *Potamogeton* sp.

INTRODUCTION

The purpose of our study was to examine the movements, home areas, and habitat selection of introduced largemouth bass (*Micropterus salmoides*) and to com-

pare their responses to native largemouth bass. The term, introduced largemouth bass, referred to fish that lived under natural conditions but were released and studied in a lake with which they were not familiar. Native largemouth bass were those familiar with the lake and presumably lived in the lake all of their lives. Intuitively, one would expect that an animal introduced into a new environment would spend some time exploring (Krebs, 1987). Winter (1976, 1977) documented such behavior for a single introduced largemouth bass in a Minnesota lake. This fish did not establish a home range in contrast to native largemouth bass which did. The behavioral responses of the introduced largemouth bass were compared to those reported for native largemouth bass (Fish and Savitz, 1983; Savitz *et al.*, 1983a,b; Tranquilli *et al.*, 1981; Warden and Lorio, 1975; Winter, 1976, 1977).

Warden and Lorio (1975) found that the initial response of largemouth bass released in a lake was to move around the lake; thereafter, fish would remain for varying lengths of time in one location or home area. They also found that largemouth bass remained in areas of shallow water which had physical cover and where there was deep water adjacent to the cover. Fish did travel between home areas, and the average daily travel distance appeared to be influenced by water temperature. Tranquilli *et al.* (1981) reported that the highest average travel distance occurred in a heated zone in Lake Sangchris; they also measured the maximum distance traveled by each of their fish. Fish and Savitz (1983) and Savitz *et al.* (1983a) examined habitat use and selection and found that largemouth bass selected ecotones, i.e., the edge of macrophyte beds. Savitz *et al.* (1983b) showed that forage availability influenced home range establishment and size for largemouth bass.

METHODS

Fish were captured by electro-fishing at the Max McGraw Wildlife Foundation in Dundee, Illinois, and by seine at Deep Lake in northern Illinois. They were transported to Loyola University and within a few weeks, radio transmitters were externally attached to the fish. The transmitters were manufactured by AVM Instrument Company, Dublin, California and weighed approximately 4.5 g. Most fish seemed to recover within an hour after transmitter attachment and this agreed with other observations (Gallepp and Magnuson, 1972; Ross and McCormick, 1981). None of the fish were in reproductive condition and they varied in size from 26.7 to 29.8 cm. Seven largemouth bass were released at the end of July and beginning of August, 1983, in Cedar Lake (114 hectares). Each fish was released one to three days after transmitter attachment.

Individual largemouth bass were placed in fish release boxes (Savitz *et al.*, 1983b) and lowered to the bottom of the lake ($\simeq$ 2 m depth) and released several hours later. Fish were released at two locations which were separated by a distance of approximately 200 m. At each location, there was a feeder (Savitz *et al.*, 1983b) from which minnows could escape. One feeder did not contain minnows; the other did, and minnows escaped from that feeder at a rate of ten minnows per hour (Savitz *et al.*, 1983b). Largemouth bass were released in this manner in order to compare the responses of introduced fishes to those previously reported for native fishes under similar conditions (Savitz *et al.*, 1983b). After the fish were released, triangulation was used to locate them. Fish were tracked several times per day for three to five days per week. The tracking began on July 25 and ended on August 26. All data

were collected during the day since there was little evidence of movement at night in this study as well as previous ones (Savitz *et al.*, 1983a). For determinations of movement distance each day, the distance between the first location of a fish on consecutive sampling days was determined.

Each fish's location was plotted on an enlarged map of Cedar Lake which included shore stations and dimensions of habitats measured in 1981. While the dimensions might have changed slightly, there were no obvious changes. The habitats were heavy macrophyte (H), primarily *Myriophyllum* sp.; light macrophyte (L), primarily *Potamogeton* sp.; sand (S), shallow areas without macrophytes; open water (O), and a minimum depth of approximately 6 m with no vegetation; and ecotone (E), 1.5 m on either side of a boundary between macrophyte beds and sand and/or open water. This boundary was usually distinct in Cedar Lake. The proportions of each habitat were 8.7% for heavy macrophyte, 8.9% for ecotones, 23.3% for open water, 27.2% for light macrophyte, and 31.9% for sand habitats.

In determining habitat utilization and habitat selection, procedures similar to those of Gilmer *et al.* (1975) and Fritzell (1978) were used. The following steps were used to compute habitat utilization. The proportions of tracked locations in each habitat for each fish in each tracking day were calculated. These proportions were added and divided by the total number of tracking days for each fish. This computation determined the average proportion of a tracking day spent in each habitat or habitat utilization (Fish and Savitz, 1983). For calculating habitat selection, the latter proportions were divided by the proportionate area of each habitat in the lake (Winter and Ross, 1982; Savitz *et al.*, 1983a). The habitat selections were ranked and a Friedman test which takes into account individual differences among the largemouth bass was used. If a significant difference in habitat selection was found, a multiple comparison test by rank was used (Zar, 1974).

The sizes of home areas were measured by the convex polygon method (Winter, 1977; Fish and Savitz, 1983), connecting the outermost fish locations to obtain the most convex polygon possible. Warden and Lorio (1975) and Hubert and Lackey (1980) felt that three or more consecutive days in one area was sufficient to indicate a home area. Fish and Savitz (1983) defined a home range with a minimum time period of five consecutive days, and this definition was followed in determining home areas in this study. Other aspects of the home areas were that the location of the fish was predictable from day to day (Ford, 1983), and fish moved about the home range (Fish and Savitz, 1983; Savitz *et al.*, 1983b).

RESULTS

Fish Movements

All of the fish had similar movements regardless where they were released; the supplementary forage did not influence their movements or use of home areas. They swam to a nearby macrophyte bed, swam along its edge for varying distances, and then remained in a particular area for two to thirteen days. Afterwards, they moved to a new area where they might remain for a short time period or, to use the description of Winter (1976), wandered around the lake. Often, two or more radio-tracked fish were located in the same home area or swimming together around the lake. Usually, these fish were not released on the same day or at the same location, and we did not know if other largemouth bass were swimming with the radio-tracked fish.

The average movements per day for our fish were between 129 and 324 m; these distances did not include those within a home area but included those between consecutive sampling days when fish were moving around the lake or between home areas. The maximum movement between consecutive sampling days varied from 290 m to 680 m. These distances were similar to those reported by other investigators (Warden and Loris, 1975; Tranquilli *et al.*, 1981). At water temperatures comparable to those during our study, Warden and Lorio (1975) reported an average movement distance between home areas of 303 m, and Tranquilli *et al.* (1981) found average daily movements from 91 m to 248 m. The maximum distances in Lake Shelbyville varied from 0.12 km to 14.34 km (Tranquilli *et al.*, 1981), but it would be impossible to approach the largest maximum distances in a small lake such as Cedar Lake (114 hectares).

Home Areas

Fish utilized home areas for variable periods of time (Warden and Lorio, 1975; Winter, 1977; Hubert and Lackey, 1980; Fish and Savitz, 1983). Six of the largemouth bass utilized a home area from five days (the minimum time period for a home range as defined by Fish and Savitz, 1983) to thirteen days (Table 1). Another largemouth bass utilized an area for two consecutive days. The median time period on a home area was 9.5 days. Home area size varied from 0.01 to 3.15 hectares (Table 1). Home areas for introduced largemouth bass were utilized for shorter time periods and were generally smaller than those for native largemouth bass. Fish and Savitz (1983) reported that native largemouth bass utilized home ranges between 0.24 and 2.07 hectares for 8 to 110 days. Savitz *et al.* (1983b) found home ranges varied from 0.05 to 0.10 hectares with increased levels of forage and in the absence of supplementary forage, home ranges increased in size to 0.79 and 7.17 hectares.

Introduced fish undoubtedly used these home areas for forage but these areas also afforded the fish protection. The home areas of LMB2 and LMB3 provided some evidence for this conclusion. Several days after LMB2 and LMB3 left their home area, LMB1, LMB2, LMB3, and LMB5 were found in this area on a day when there were strong winds and heavy wave action.

Habitat Selection

There was a significant difference ($x^2 = 25.94$, $p < 0.001$) in habitat selection: $\underline{E\ H\ LS\ O}$. Ecotone had the highest ranked selection which was significantly different ($p < 0.01$) from other habitats. The heavy macrophyte habitat was selected less than the ecotone but had significant ($p < 0.01$) greater selection than the remaining habitats. Ecotones were utilized 51% to 69% of an average tracking day, and heavy macrophytes were usually the second most utilized habitat (Table 2). When largemouth bass were located in heavy macrophytes or along ecotones, they were usually found among the stems of a broad-leafed *Potamogeton* sp. which occurred in small patches. Warden and Lorio (1975) found that most home areas were located where there was physical cover and the same conclusion was apparent for the introduced largemouth bass. Light macrophyte and sand habitats were not significantly different ($p > 0.05$) and LMB1 was the only fish located in open water.

DISCUSSION

In previous studies, largemouth bass movements and home areas were influenced by water temperature (Warden and Lorio, 1975; Tranquilli *et al.*, 1981), season (Ross and Winter, 1981), cover (Warden and Lorio, 1975), forage availability (Savitz *et al.*, 1983b), familiarity of fish with the lake (Winter, 1976). Undoubtedly, other factors such as fish size and lake size which might influence largemouth bass movements will be documented. In comparing movements, habitat selection, and home areas of our introduced largemouth bass to those of native largemouth bass, differences and similarities in factors which might influence the results must be discussed.

Our introduced largemouth bass were released at the same locations, in the same manner, and during the same months (July and August) as native largemouth bass in 1981 (Savitz *et al.*, 1983b). In addition, water temperatures were similar and the same investigator did the majority of the radio-tracking for the introduced largemouth bass and native largemouth bass (Savitz *et al.*, 1983b). The introduced fish did not respond in the same manner as the native fish. The difference might have been caused by some unrecognized factor or the introduced fish might not have been as aware of the differences in forage availability as those fish familiar with the lake. Higher levels of supplementary forage might have elicited a similar response as that with native largemouth bass. From a fisheries management perspective, stocking largemouth bass at the supplementary forage levels used in this study would not result in home range establishment in the vicinity of the feeder. Usually, when largemouth bass were stocked in lakes, fish size and stocking procedure were different than used in this study.

The movements of our introduced fish were similar to those reported by other investigators. Winter (1976) found that an introduced largemouth bass wandered around a lake, but was located in a small area, 0.4 hectare, for five consecutive days. Warden and Lorio (1975) and Tranquilli *et al.* (1981) found similar average movement distances as occurred in our study.

The habitat utilization and selection of introduced largemouth bass were similar to that of native largemouth, but there were also some differences. Introduced fish utilized ecotone and heavy macrophyte habitats with little difference between individual fish. Native largemouth bass were more frequently located in shallow sand bottom area and to a somewhat lesser extent in the ecotone habitat (Fish and Savitz, 1983). In the calculation of habitat selection, the area of each habitat was important, and, since the ecotone habitat had a much smaller area, the habitat selection for the ecotone was greater than that of shallow sandy bottom areas. However, there was no significant difference in selection between these habitats (Savitz, *et al.*, 1983a). Also, among native largemouth bass, there were individual differences in habitat utilization; two were more frequently located in heavy macrophytes (Fish and Savitz, 1983). The data on native fishes were collected in different months, May through December, than the introduced fish; however, no seasonal differences in habitat utilization of native fish were obvious (Fish and Savitz, 1983). It appeared that the introduced fish needed physical cover.

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Table 1. Home range sizes and residence time for stocked largemouth bass in Cedar Lake (LMB 5 never established a home range).

Fish	Home Range (hectares)	Residence Time (days)	Dates of Home Range
LMB 1	1.93	11	July 25 - August 4
LMB 2	0.01	5	August 1 - August 5
LMB 3	0.01	5	August 1 - August 5
LMB 4	0.10	10	August 2 - August 11
LMB 6	0.14	9	August 3 - August 11
LMB 7[a]	3.15	13	August 10 - August 22

[a]LMB 7 was caught by fisherman on evening of August 22.

Table 2. Habitat utilization by each fish presented as percent of an average tracking day in each habitat

Fish	Number of tracking locations	Number of tracking days	E	H	L	S	O
LMB 1	44	19	57.0	13.1	7.9	16.7	5.3
LMB 2	41	18	58.3	16.7	11.1	13.9	—
LMB 3	40	18	68.5	21.7	4.2	5.6	—
LMB 4	40	16	61.4	16.6	18.8	3.2	—
LMB 5	37	15	57.1	32.3	3.3	7.3	—
LMB 6	35	14	60.7	14.3	21.4	3.6	—
*LMB 7	26	9	50.9	6.4	13.0	30.7	—

*This fish was caught by fisherman in the evening on August 22, 1983.

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EFFECTS OF SEASON AND SUBSTRATE ON AVAILABILITY OF DRIFT FOR FISH IN A SMALL WARMWATER STREAM

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ABSTRACT

Midday drift samples were collected through summer and autumn from two reaches of Jordan Creek, a second-order stream in east-central Illinois. The two study reaches differed primarily in gradient and substrate characteristics, with silt-sand predominating in the low-gradient reach, and gravel-cobble predominating in the high-gradient reach. Aquatic insect larvae, especially dipterans, were the most abundant invertebrates in samples from the gravel-cobble reach, but were uncommon in drift from the silt-sand reach, which was composed mostly of small copepods and cladocerans. Invertebrate abundance and size declined markedly through the summer in both study reaches, then increased through autumn. Insect larvae were virtually absent from the silt-sand drift in October, but were always present in drift from the gravel-cobble reach. On the basis of invertebrate size and abundance, the gravel-cobble reach provided a more dependable food base for Jordan Creek fishes than did the silt-sand reach. Stream modifications that alter substrate composition may increase the severity of seasonal food shortages for fish, and contribute to declining diversities in stream fish assemblages of the Midwest.

INTRODUCTION

Because aquatic invertebrates represent a major food resource for most temperate stream fishes, spatio-temporal dynamics of invertebrate abundance can have

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important implications for fish trophic ecology and community structure. Seasonal changes in invertebrate abundance are probably regulated by cycles of emergence and reproduction, which typically feature high abundance in spring and low abundance in summer for Illinois streams (Angermeier, 1982; Schlosser and Toth, 1984). Seasonal fluctuations in food availability often affect the foraging success of stream fishes (Mathur, 1977; Angermeier, 1982; 1985; Schlosser and Toth, 1984), and may therefore influence growth and survival. Spatial variation in invertebrate abundance and composition often reflects habitat characteristics such as current velocity and substrate type. For example, invertebrate abundance and production are typically lower in sand than in gravel and cobble substrates (Wene and Wickliff, 1940; Mackay and Kalff, 1969; Minshall and Minshall, 1977). Silt and sand substrates have probably always been common in low-gradient streams of Illinois, but have become increasingly more common due to watershed management practices such as stream channelization (Griswold et al., 1978; Schmal and Sanders, 1978) and row-crop agriculture. Long-term shifts in substrate composition of streams are likely to induce changes in fish community structure and declines in stream productivity.

The abundance of drifting invertebrates is commonly used to measure availability of food for fish (Mendelson, 1975; Mathur, 1977; Angermeier, 1982). Drift rates are regulated by light intensity (Holt and Waters, 1967), and are typically greatest shortly after dusk (see Muller, 1974 for a review). This pattern is apparently a behavioral adaptation for avoiding visually-oriented predators such as fish. However because most warmwater stream fishes feed most actively in daylight (White and Wallace, 1973; Mathur, 1977; Baker and Ross, 1981; Surat et al., 1982; Matthews et al., 1982) diurnal drift is a more appropriate measure of the food available to fish than nocturnal drift.

This study was designed to examine summer and autumn patterns of invertebrate abundance and composition in two reaches of a small Illinois stream. We were particularly interested in comparing the dependability of invertebrates as a food resource for fishes inhabiting the two reaches. We restricted our study to summer and autumn because previous studies indicated that food shortages for stream fishes are most severe during these seasons (Mathur, 1977; Angermeier, 1982; Schlosser and Toth, 1984). Patterns of invertebrate dynamics are discussed with respect to their potential impact on fish community structure.

STUDY STREAM

Jordan Creek is a second-order tributary of the Salt Fork of the Vermilion river in east-central Illinois (USA). The stream is 17 km long, and drains a glaciated basin of 30 km^2 (Larimore, 1961). Riparian and channel characteristics change dramatically from the channelized headwaters to the relatively undisturbed downstream areas (Schlosser and Karr, 1981). Sampling locations were selected to represent conditions in two wooded reaches along the upstream-downstream gradient. The upstream sample site (silt-sand reach) featured a narrow (5-10 m) strip of riparian vegetation comprising mostly multiflora rose (*Rosa multiflora*), osage orange (*Maclura pomifera*), and hackberry (*Celtis occidentalis*). Land use beyond the riparian zone was intensive corn and soybean agriculture. Gradient of the 4 m wide channel was slight (0.7 m/km) and pool-riffle structure was poorly developed. Bottom substrates were 85% silt and sand, and mean depth was 19 cm (Angermeier, 1983). In contrast, the downstream sample site (gravel-cobble reach) was bordered by 10-50 m of ripar-

ian woodland which included maples (*Acer* spp.), oaks (*Quercus* spp.), and sycamore (*Plantanus occidentalis*). The channel was wider (8 m) and gradient was steeper (4.0 m/km), with well developed pools and riffles. Bottom substrates were only 25% silt and sand with 52% gravel and cobble; mean depth was 27 cm (Angermeier, 1983). This reach, 4 km from the silt-sand reach, has never been channelized. Both reaches of Jordan Creek support a diverse fish fauna (25-30 species) composed largely of cyprinids, catostomids, and centrarchids (Larimore, 1961; Angermeier, 1983).

MATERIALS AND METHODS

Invertebrates were sampled with a 30.5 × 45.5 cm tapered drift net with 363 μm mesh. One net was staked to the center of the stream bottom at the downstream end of a riffle in both study reaches. Samples were collected from the same location during each sampling period. Samples were collected at midday (10:45-13:45) for 1 hr. during the second week of June, July, September, October, November, and December 1983. For all samples except those collected in June and December from the silt-sand reach, drift net height exceeded water depth (i.e., the entire water-column was sampled). Depth of the water column entering the net was measured to the nearest 1.0 cm. Current velocity at the mouth of the net was estimated by repeatedly timing a float traveling 1 to 3 m in front of the net. Depth and velocity measurements were then used to estimate volume of water sampled. Because surface velocity exceeds average velocity of the water column, this method overestimates the volume of water sampled and underestimates the concentration of invertebrates. However, the method was used consistently for all collections, and depth differences between the two sample sites were slight (<15cm); thus, the inaccuracy of our velocity estimates should not influence our interpretation of comparisons of invertebrate abundance from different months and sites.

Invertebrates were preserved immediately in 15% formalin. Samples were then divided into 8 subsamples using a device similar to that of Waters (1969). Previous work with this device indicated that subsamples were consistently similar (Angermeier, 1983). All invertebrates from one subsample were sorted to order beneath a dissecting microscope and measured to the nearest 0.1 mm total length (excluding caudal processes) with an ocular micrometer. All terrestrial forms were regarded as a single taxon. Invertebrates were assigned to one of three arbitrary size groups on the basis of total length: small (0.1-1.9 mm), medium (2.0-3.9), and large (4.0-12.0 mm). Size frequency distributions from different months and sites were compared using the G-test for independence with Williams' correction (Sokal and Rohlf, 1981).

RESULTS

Surface current was always faster in the gravel-cobble reach ($\bar{x}$ = 0.50 m/s; range = 0.27 to 0.75 m/s) than in the silt-sand reach ($\bar{x}$ = 0.32 m/s; range = 0.11 to 0.55 m/s). Differences in taxonomic composition between the study reaches reflected differences in current velocity and associated substrates. Dipterans (mostly chironomids) were the most abundant taxon in drift samples from the gravel-cobble reach; their relative abundance ranged from 78% in June to 21% in December. Copepods were the most abundant taxon only in December, when they made up 60% of the invertebrates captured. Other taxa, including Trichoptera, Ephemeroptera, and Cladocera, were also occasionally common in the gravel-cobble samples.

In contrast, copepods were the most abundant taxon in the silt-sand reach, making up from 22 to 100% of the invertebrates captured. Cladocerans and water mites (Hydracarina) were also common in June and July. Dipterans never made up more than 20% of the total invertebrates; trichopterans and ephemeropterans were always rare and never contributed more than 2.5% of the invertebrates in a sample.

Abundances of all major invertebrate taxa declined markedly between June and September, then increased in late autumn in both study reaches (Fig. 1). Numbers of drifting invertebrates other than zooplankton (copepods and cladocerans) declined to virtually zero in the October sample from the silt-sand reach, while non-zooplankton drift were consistently observed through autumn in the gravel-cobble reach (Fig. 1). Non-zooplankton invertebrates were more abundant in the gravel-cobble reach than the silt-sand reach for all months except July and November.

Seasonal patterns of invertebrate size paralleled patterns of abundance. Drifting invertebrates in the gravel-cobble study reach were larger in June-July than in September-October or November-December (Fig. 2; G-test; $P < 0.005$). The small size of invertebrates in November-December was largely due to a sharp autumnal increase in zooplankton abundance (Fig. 1); size distributions of non-zooplankton invertebrates from June-July and November-December were not different (G-test; $P > 0.05$). Size distribution of invertebrate drift in the silt-sand reach changed little through the summer and autumn, and was always predominated by small zooplankton (Fig. 2). Invertebrates from November-December were slightly smaller than those from June-July (G-test; $P < 0.05$), but no seasonal shift in size distribution were observed for non-zooplankton invertebrates (G-test; $P > 0.05$). Month-by-month comparisons with the G-test indicated that invertebrates were always larger in the gravel-cobble reach than in the silt-sand reach, although sample sizes were too low in September and October to establish significance.

In summary, invertebrate drift in the silt-sand reach of Jordan Creek was predominated by small zooplankton, while drift in the gravel-cobble reach was predominated by larger aquatic insects. Invertebrate abundance declined markedly through the summer in both reaches, but insects become especially scarce in the silt-sand reach.

DISCUSSION

Spatio-temporal patterns of stream invertebrate abundance are extremely complex because they integrate numerous factors, including seasonality, food and habitat quality, and predation pressure. Annual cycles of stream invertebrates typically feature highest abundance in spring and low abundance in summer (Hynes, 1970), largely resulting from patterns of emergence, reproduction, and recruitment. These cycles may have evolved in response to large autumnal inputs of allochthonous organic material (mostly leaves), a primary food resource for stream invertebrates (Cummins and Klug, 1970). Invertebrates in both reaches of Jordan Creek exhibited patterns of seasonal abundance consistent with this typical pattern. Invertebrates are also generally less abundant in substrates predominated by silt and sand than in substrates composed mostly of gravel and cobble (Wene and Wickliff, 1940; Mackay and Kalff, 1969; Minshall and Minshall, 1977). This trend may result from the relative instability of finer substrates (Slack, 1955; Luedtke and Brusven, 1976; Schmall and Sanders, 1978), or their lack of interstitial surfaces available for colonization by invertebrates. Although total invertebrates were not more abundant in the gravel-cobble reach than in the silt-sand reach, aquatic insects (e.g. dipterans)

were generally more abundant in the gravel-cobble reach. Schlosser (1982) observed similar patterns in comparisons of drift samples from the same two study areas of Jordan Creek. In his study, insects were 1.5-3.5 times more abundant in the gravel-cobble reach than in the silt-sand reach from June through November. Our study indicates that small zooplankton, which reside above (rather than on) the stream bottom, were more abundant in the silt-sand reach. Furthermore, aquatic insects virtually disappeared from the silt-sand drift in October, but were always available in the gravel-cobble reach.

Most fish species that inhabit small midwestern streams depend largely on aquatic invertebrates for food (Pflieger, 1975; Smith, 1979; Trautman, 1981). Thus, foraging patterns and growth rates of stream fishes should be sensitive to spatio-temporal dynamics of invertebrate abundance. For example, some species in Jordan Creek, especially cyprinids exhibit sharp declines in foraging success through the summer and fall (Angermeier, 1982; 1985), apparently in response to declines in invertebrate availability. The late-summer scarcity of invertebrates is exacerbated for insectivorous fish because of the pulsed entry of young-of-year fish into the community, as well as high metabolic rates induced by high temperatures. Not only were fewer invertebrates available as food for Jordan Creek fishes through the summer, but invertebrate size (a measure of calorie content) also declined through the summer. Most Jordan Creek fishes preferrably consume relatively large invertebrates such as insect larvae (Angermeier, 1982), presumably because of their greater energetic profitability (Werner et al., 1983). Of the ten common species studied by Angermeier (1985), zooplankton made up at least 10% of the prey eaten for only three species. Thus, results from this study suggest that the gravel-cobble reach provided a more dependable food base for fish than the silt-sand reach. This hypothesis has been corroborated for some species (especially cyprinids), which consumed more or larger prey in the gravel-cobble reach than in the silt-sand reach (Angermeier, 1985).

Streams in agricultural watersheds of the Midwest are subjected to numerous disturbances, including clearing, snagging, and channelization. These channel modifications typically cause shifts in substrate composition toward fine, unstable particles such as silt and sand (Griswold et al., 1978; Schmal and Sanders, 1978), and affect all levels of biological production (Marzolf, 1978). In combination with increased temperatures due to removal of shade, food scarcities associated with fine substrates may create extremely stressful conditions for insectivorous fishes during low-flow periods of summer and autumn. Food availability is closely linked to rates of fish growth and production, and may ultimately be a determinant of community structure. Thus, widespread disruptions of food and habitat resource bases due to sediment loads and stream alterations have probably contributed to the declines in diversity and changes in trophic composition observed in Midwest fish faunas throughout this century (Pflieger, 1975; Smith, 1979; Trautman, 1981; Karr et al., 1985). Development of management strategies to halt this trend will require identification of conditions under which growth and survival of fishes are limited, and how anthropogenic impacts increase the severity of those limitations.

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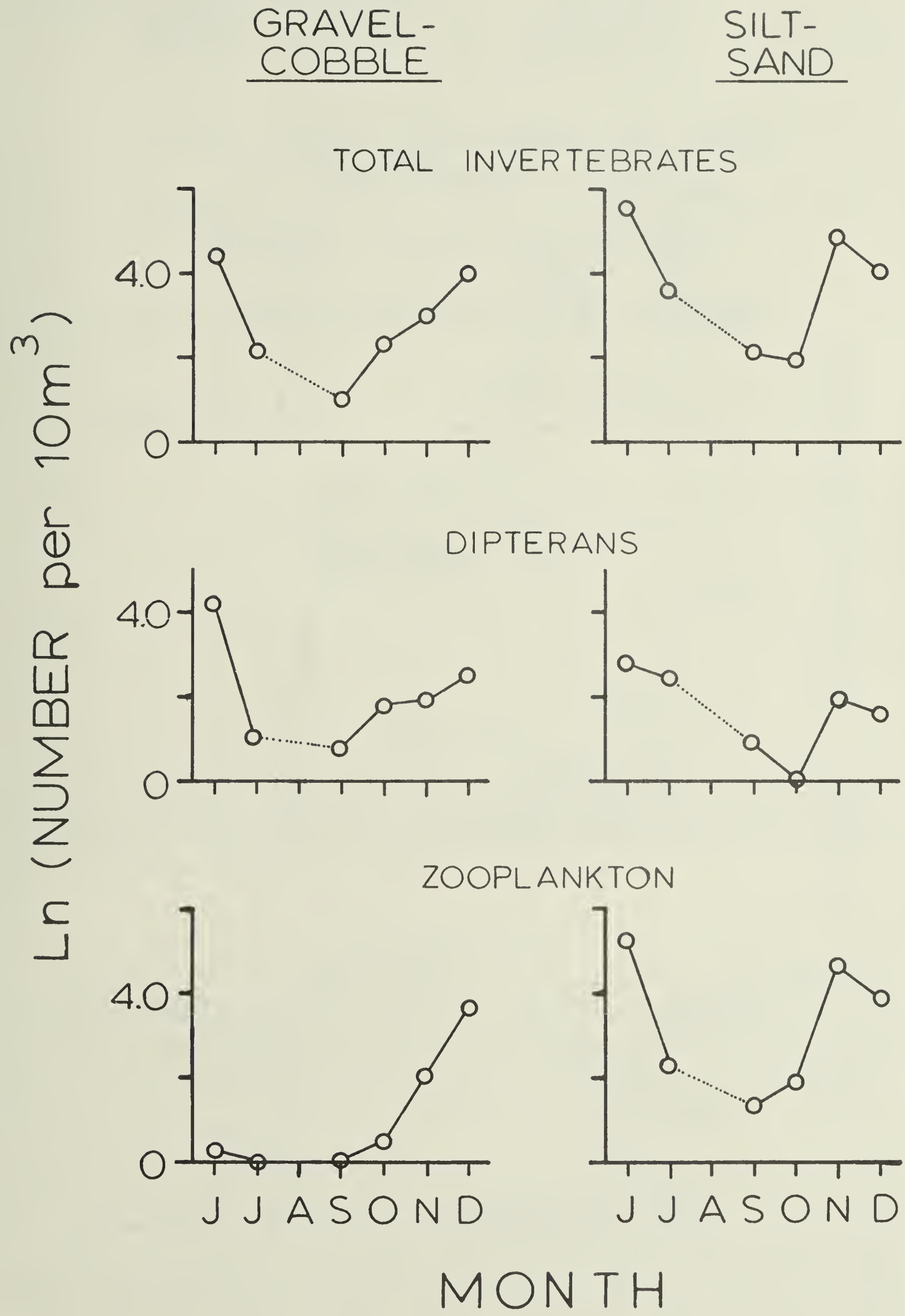

Fig. 1. Numbers of invertebrates captured in midday drift samples from two study reaches of Jordan Creek through the summer and autumn of 1983. Zooplankton comprised copepods and cladocerans. No samples were collected in August.

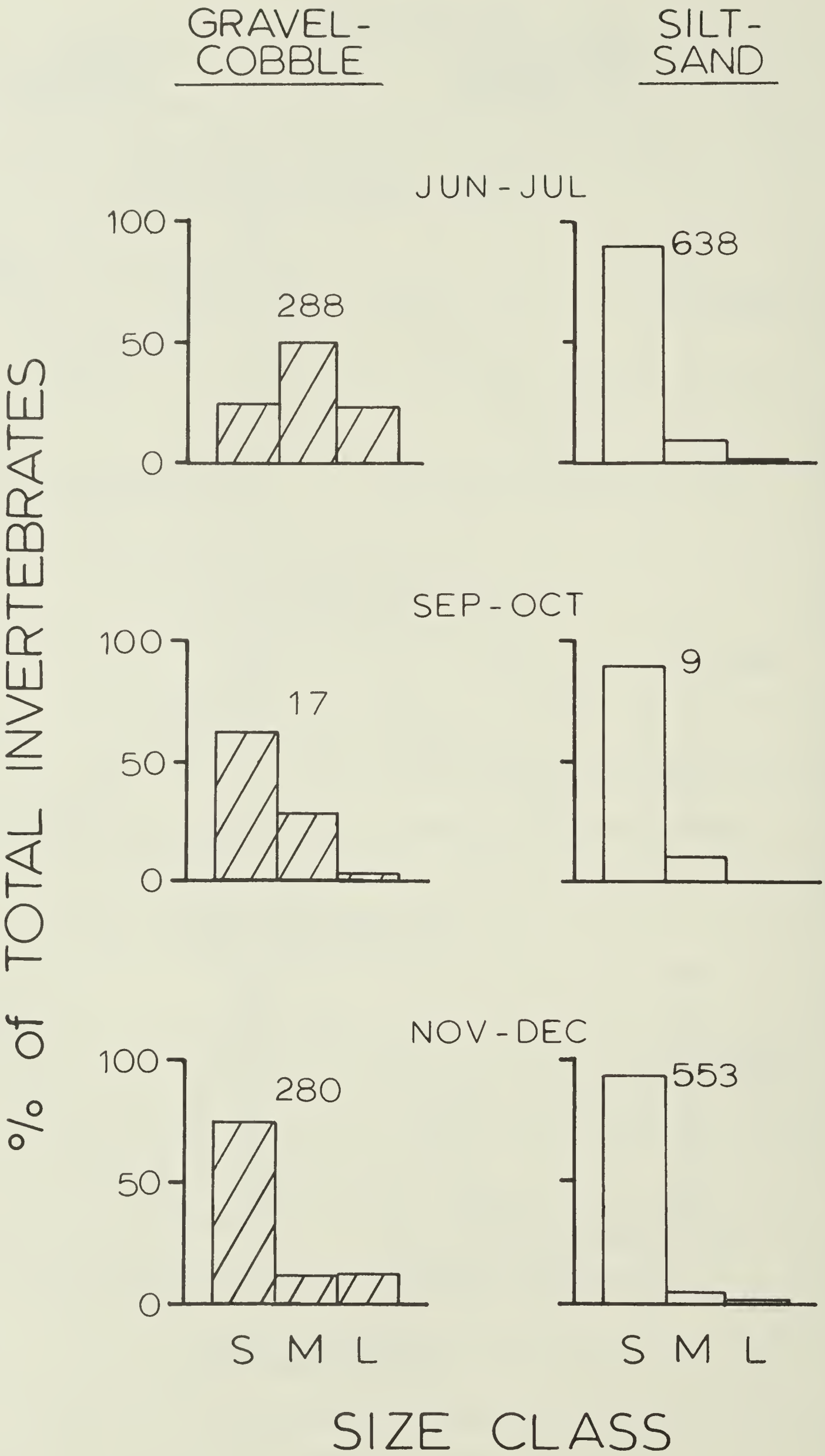

Fig. 2. Size frequency distributions of drifting invertebrates from two study reaches of Jordan Creek. Three size classes were distinguished on the basis of body length: small (<2.0 mm), medium (2.0-3.9 mm), and large (≥4.0 mm). Numbers on each graph indicated the total number of invertebrates used to construct the graph.

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THE FIRST RECORD OF THE SOUTHEASTERN SHREW (*SOREX LONGIROSTRIS*) IN PIKE COUNTY, ILLINOIS

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ABSTRACT

A new record of occurrence of the Southeastern Shrew (*Sorex longirostris*) has been documented. Four individuals were trapped in Pike County, Illinois. This indicates a continous range with populations previously collected in northeastern Missouri and southwestern Illinois.

INTRODUCTION

In October, 1981 four specimens of the Southeastern Shrew, *Sorex longirostris*, were captured in pit traps. Three specimens were collected 200m south of Valley City, Pike County, Illinois, along Flint Creek. The fourth specimen was captured 2km south of Valley City, in the Pike County Conservation Area. These are the first known records in Pike County, indicating their range to extend northwestward into west-central Illinois.

The Southeastern Shrew has been reported from various counties in southern Illinois. George (1977) reported specimens from Jackson, Johnson, Union and possibly Williamson Counties. Hoffmeister and Mhor (1972) reported specimens from Alexander, Coles, Fayette and Johnson Counties. Klimstra and Roseberry (1969) reported specimens from Union and Pope Counties. Wood (1910) reported the Southeastern Shrew in McHenry County, however, subsequent investigation found this specimen to be *Sorex cinerius* (French, 1980). Parmelle (1967), tentatively identified remains of at least 27 individuals from deposits in a fissure in Monroe County.

Mock and Kivett (1980) have reported captures of the Southeastern Shrew in Adair, Schuyler, and Macon Counties of northeastern Missouri. Prior to Mock and Kivett's work, the only record was from Barry County, 400km southwest (Brown, 1961).

The Pike County specimens in part fill the gap between these records from southwestern Illinois and northeastern Missouri.

The Pike County specimens have been added to the mammal collection at Western Illinois University.

ACKNOWLEDGEMENTS

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MACROLICHEN FLORA OF JACKSON COUNTY, ILLINOIS

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ABSTRACT

Keys, habitat descriptions, and abundance information are provided for the 84 species of macrolichens documented by voucher specimens from Jackson County, Illinois. Brief descriptions of more than 25 additional macrolichen taxa not known from the county but occurring in other counties in the region also are included.

INTRODUCTION

This paper is a floristic treatment of the macrolichens of Jackson County, Illinois. It includes information concerning their habitats and abundance within the county; also included is a key to the genera of Jackson County macrolichens, and keys to species for each genus in which more than one species is represented. For macrolichens known commonly from nearby counties, but not recorded specifically from Jackson County, brief descriptions are included under the taxon which they most closely resemble.

No previous work has been devoted specifically to Jackson County lichens, though several Jackson County collections are cited in Skorepa (1966, 1973 & 1977). Stotler (1976) conducted a study of saxicolous bryophyte and macrolichen associations in Little Grand Canyon, a natural area in the southwestern sector of the county. Winterringer & Vestal (1956) described the rock-ledge vegetation of southern Illinois, though none of their sampling study areas were located within Jackson County. Skorepa's (1973) dissertation on the taxonomy and ecology of the lichens of southern Illinois is perhaps one of the most interesting and insightful lichenological floristic works to date, but it contains only desultory references to Jackson County.

With an area exceeding 1554 square kilometers (600 square miles), Jackson County is the largest county in southern Illinois. According to Voigt and Mohlenbrock (1964) this county is physiographically one of the most diverse in southern Illinois, and contains examples of plant communities, topography, and substrates representative of much of the region.

According to Schwegman (1973), four of the six natural divisions described for southern Illinois occur in Jackson County. Most of the northern half of the county is in the Southern Till Plain Division. The extreme northwestern edge of the county and a small portion in the Pine Hills are in the Ozark Division, while most of the dissected southern sector is in the Shawnee Hills Division. A broad zone along the western edge of the county is in the Lower Mississippi River Bottomlands Division.

The macrolichen flora of Jackson County, Illinois is known to consist of 84 species, nearly all of which have phytogeographic affinities to the eastern United States. Our own studies of the region suggest, however, that the macrolichen floras of Jackson County and southern Illinois have more in common with those of the Missouri Ozark region rather than with those parts of the midwest which were heavily glaciated and supported tall grass prairie in the presettlement era. Data regarding the macrolichens of DuPage County in northern Illinois (Wilhelm & Lampa, unpublished data) and Bennett Spring State Park in southwestern Missouri (Ladd & Wilhelm, 1983) reveal a Sorensen coefficient of similarity (Sorensen, 1948) of 0.43 between the lichen floras of Jackson County and DuPage County, and a coefficient of 0.68 between Jackson County and Bennett Spring State Park. Both areas are about equally remote from Jackson County.

SUBSTRATES

There are three major substrates available for macrolichen colonization in Jackson County: saxicolous, terricolous, and corticolous. Some species of macrolichens inhabit lignicolous substrates as well. Sound and undecayed lignin is inhabited by several lichen species otherwise characteristic of corticolous substrates. As lignin decays it tends to be inhabited by those lichens which frequent terricolous substrates. Lignin does not in and of itself provide the substrate for a discrete macrolichen community in Jackson County. Although Skorepa (1973) listed *Cladonia bacillaris* and *C. coniocraea* as occurring on lignin only, we have found them occasionally on lightly shaded sandstone as well.

Saxicolous substrates consist primarily of sandstone walls, ledges, and boulders. Limited exposures of limestone occur near Grand Tower and along Kinkaid Creek, as well as minor outcrops in a few other areas. The few shale exposures in the county rapidly weather into masses of small resistant flakes and are too unstable for lichen colonization.

Terricolous substrates consist of humus, decayed wood, and soils derived from alluvium, loess, glacial till, and the weathering of sandstone, limestone, and shale. Some upland sites in the county have cherty soils with a high proportion of chert residuum. Detailed discussions on the geology and soils of Jackson County can be found in Harris, *et al.* (1977), Klubek, *et al.* (1983), and Mohlenbrock (1983).

Corticolous substrates available for macrolichens in the county are extensive and varied. In presettlement times much of Jackson County was forested (Schwegman, 1973). Some fairly extensive prairie areas occurred in the northeastern portion of

the county, and smaller prairie, glade, and savanna areas were interspersed throughout the county. A complex of small hill prairies occurred along the Mississippi River in the southwestern part of the county. Forests and more open vegetation types provided an array of moisture, light intensity, and exposure conditions, all of which factors create a wide range of conditions for macrolichen development.

Post-settlement disruptions of the natural vegetation, including clearing, post-clearing successional processes, introduction of Old World plant species, fire suppression, and air pollution, have resulted in now greatly altered vegetation patterns in the county.

The extent to which anthropogenics have had an effect on the autochthonous lichen flora is uncertain; indeed, the relationship between present patterns of corticolous macrolichen occurrence and that existing in presettlement times is impossible to ascertain. It is interesting to note, however, that several taxa, such as *Physcia millegrana*, almost invariably occur on trees in disrupted or disturbed communities, with autecological patterns similar to those of our weedy vascular flora. Many other lichens, such as *Anzia colpodes*, are found only in communities which exhibit a high degree of natural floristic integrity.

THE FLORA

The body of this work begins with a key to the genera of macrolichens of Jackson County, followed by an alphabetically arranged series of generic entries. The generic entries contain keys to species where necessary and are followed by species entries which provide information regarding each species' abundance and habitat within the county. The species entries also include morphological and chemical information relevant to lichen identification. Species concepts and nomenclature, for the most part, follow Hale (1979), as do the standards for measuring lobe width and abbreviations for reagents used in chemical tests. If the names used by Hale (1969) are different from those employed in his second edition, they are provided as a synonym under the species entry to which it is relevant. For each species listed from the county a representative voucher is cited, along with the standard acronym, as used by Index Herbariorum, of the institution at which the specimen is housed. In a few cases, specimens cited by Skorepa (1966 & 1977) could not be located in the herbarium of Southern Illinois University. Skorepa (1973) infers that they are at either the University of Tennessee, the University of Wisconsin, or in his personal herbarium.

KEY TO THE GENERA

A. Thallus gelatinous, dark brown to blackish or dark slate gray; medulla absent.
  B. Thallus subcrustose, not distinctly lobed; on limestone. . . . *Placynthium*
  B. Thallus foliose and distinctly lobed; on various substrates.
    Thallus gray to brown; surface smooth or finely wrinkled but never pustulate, often shiny; isidia present, or thallus with fine coralloid branches. . . . *Leptogium*
    Thallus black to blackish-olive, or if brown then without isidia, never with coralloid branches; surface flat to pustulate, dull; isidia present or absent. . . . *Collema*
A. Thallus not gelatinous, variously colored; medulla present.
  C. Thallus squamulose or fruticose.
    D. Thallus distinctly fruticose.
      E. Thallus strongly flattened and two-sided; squamules absent. . . . *Ramalina*

E. Thallus with rounded podetia; squamules present or absent.

F. Thallus branched, anchored by a central stalk, with a distinct dense central cord; squamules absent. . . . *Usnea*

F. Podetia (thallus) simple or branched, usually fistulose, without a distinct central cord; squamules present or absent.

Podetia much-branched and characterized by a dull, fibrous, ecorticate surface; squamules absent. . . . *Cladina*

Podetia simple or branched, the cortex continuous, areolate, sorediate, or decorticate, but not fibrous as above; squamules present or absent. . . . *Cladonia*

D. Thallus squamulose.

Squamules flat, brown, dark beneath, appressed. . . . *Dermatocarpon*

Squamules more or less erect, white or yellowish beneath, not appressed. . .*Cladonia*

C. Thallus distinctly foliose to umbilicate.

G. Perithecia present; thallus umbilicate and centrally attached; upper surface brown to gray or blackish. . . . *Dermatocarpon*

G. Perithecia absent; thallus not umbilicate; upper surface variously colored.

H. Thallus densely fibrous or tomentose beneath and with evident veins; lobes broad; upper surface dark brown. . . . *Peltigera*

H. Thallus never both densely fibrous-tomentose and with evident veins beneath; lobes various; upper surface variously colored.

I. Thallus orange, yellow, yellowish-green, or yellowish-gray, never ciliate.

J. Thallus orange; upper cortex K + deep purple. . . . *Xanthoria*

J. Thallus not orange; upper cortex K – .

K. Lobes finely divided into segments less than 1 mm broad; medulla P – .

Thallus sorediate, adnate on corticolous substrates; rhizines present. . . . *Candelaria*

Thallus without diaspores, tightly appressed to saxicolous substrates; rhizines absent. . . . *Lecanora*

K. Lobes evidently broader than 1 mm, not finely divided; medulla P + red or orange.

Thallus sorediate or with coarse sub-sorediate pustular isidia; upper cortex dull; lobes broad and blunt; corticolous or saxicolous . . . *Pseudoparmelia*

Thallus esorediate; isidia absent, or if present then small and fine; upper cortex shiny; lobes prevailingly narrow and strap-like; saxicolous. . . *Xanthoparmelia*

I. Thallus without an orange or yellowish-green tint, or if rarely so then the lobe margins distinctly long ciliate.

L. Upper surface distinctly grayish, the cortex characteristically broken by white pores; medulla C + red. . . . *Parmelia*

L. Upper surface of various tints, the cortex lacking white pores; medulla (in our species) C – or C + yellowish.

M. Thallus lobes relatively broad, mostly more than 5 mm; lower surface usually with a broad rhizine-free zone near the margin. . . . *Parmotrema*

M. Thallus lobes prevailingly less than 5 mm broad; rhizines, if present, extending nearly or quite to the margin.

N. Rhizines nearly or quite absent; thallus lobes confluent and tightly adnate to the substrate.

Cortex K + yellow, whitish mineral gray; saxicolous. . . . *Dirinaria*

Cortex K – , brown or brownish-gray; corticolous. . . . *Physciopsis*

N. Rhizines usually present and obvious; otherwise without the above combination of characters.

O. Lower surface white, light tan, or suffused with orange.

P. At least some soralia marginal or apical, linear or crescent-shaped; lower surface fibrous to smooth and corticate, typically with a few long rhizines projecting along the margins. . . . *Heterodermia*

P. Soralia laminal, marginal, or absent, not linear; lower surface smooth and corticate; rhizines not noticeably projecting.

Q. Thallus gray, the lobes mostly more than 3 mm broad; medulla C + red. . . . *Parmelia*

Q. Thallus whitish-gray to light brown, the lobes mostly less than 2 mm broad; medulla C – .

Upper cortex K – ; soredia absent. . . . *Anaptychia*

Upper cortex K + yellow, or if K – , then sorediate. . .*Physcia*

O. Lower surface dark gray to blackish throughout, or light-colored near the margins only.

R. Lobes narrow and linear, appearing thick and inflated; lower surface densely black-tomentose. . . . *Anzia*

R. Lobes various, not appearing thick and inflated; lower surface not densely black-tomentose.

S. Medulla distinctly yellow and the cortex K – , or salmon-colored and the cortex K + yellow; thallus sorediate and usually pruinose. . . . *Pyxine*

S. Medulla white (and cortex K – or K + yellow), or diffusely pale yellow (and cortex K + yellow), or bright red or orange (and the cortex K –), but not distinctly yellow or salmon; soredia and pruina present or absent.

T. Upper surface conspicuously foveolate, reticulate-ridged, especially on the lobes. . . . *Pseudoparmelia*

T. Upper surface smooth, without strong reticulate markings.

U. Thallus mineral gray or grayish green; cortex K + yellow; pruina absent.

Medulla usually pale yellow and K + yellow or yellow turning red; rhizines simple; soredia present, or if absent the medulla P + orange. . . . *Parmelina*

Medulla white, K – , P – ; some of the rhizines branched; soredia and isidia absent. . . . *Hypotrachyna*

U. Thallus whitish-gray to light tan, brownish-gray, or brown; cortex K – ; pruina absent or present.

Pruina conspicuous; soredia in linear marginal soralia. . . . *Physconia*

Pruina absent or only faintly developed; soredia various or absent, but not in linear soralia.. . . *Phaeophyscia*

Anaptychia Koerb.

Anaptychia palmulata (Michx.) Vain.

Cortex K – ; without diaspores
Medulla K – , C – , KC – , P –

Occasional on the bases of deciduous trees, shaded sandstone, and on moss over rocks and trees. Some authors spell the epithet "palmatula". Wilhelm 8440 MOR.

Anzia Stizenb.

Anzia colpodes (Ach.) Stizenb.

Cortex K + yellow; without diaspores
Medulla K – , C – , KC – , P –

Rare on the trunks of oak trees in mature closed forests. Hatcher 1365s SIU.

Skorepa (1966) reported *Coccocarpia cronia* (Tuck.) Vain. from Jackson County, but his specimen (#1504) could not be found; this specimen is not cited in his dissertation (Skorepa, 1973). It is known from nearby counties, and differs notably from *Anzia colpodes* in that it is isidiate.

Candelaria Mass.

Candelaria concolor (Dicks.) B. Stein

Cortex K – ; sorediate

Medulla K – , C – , KC – , P –

Very common on a wide variety of deciduous trees and on cedar, in towns, residential areas, and along roadsides and forest edges; often associated with *Parmelia rudecta* and *Physcia millegrana*. Wilhelm 8334 MOR.

Cladina (Nyl.) Harm.

Cladina subtenuis (Abb.) Hale & W. Culb.

Podetia K – , C – , KC – , P + red; without diaspores

Frequent on sandstone and well-drained soils in exposed to lightly shaded situations. = *Cladonia subtenuis* (Abb.) Evans. Wilson 2667 SIU.

A larger, pure white species, *C. rangiferina* (L.) Harm., is known from southern Illinois and has been cited from Jackson County [as *Cladonia rangiferina* (L.) Wigg.] by Stotler (1976); however, no confirming specimens have been found. It should be sought in well-drained acidic soils.

Skorepa (1966) cited *Cladonia sylvatica* (L.) Hoffm. from Jackson County, but no confirming specimens have been located. Nomenclaturally this translates into *Cladina arbuscula* (Wallr.) Hale & W. Culb., which we have collected from elsewhere within the region. It is similar to *C. subtenuis* but is characterized by the strongly secund ultimate branches. The only *Cladina* species included in Skorepa (1973) are *C. subtenuis* and *C. rangiferina*.

Cladonia Wigg.

1. Podetia elongated, usually slender and much-branched; squamules present or absent.
   2. At least some squamules present, particularly toward the base and on the lower branches of the podetia; podetia grayish.
      Podetia unbranched or very sparsely branched, UV + blue-white, P – ; primary squamules numerous. . . . *C. squamosa*
      Podetia repeatedly branched, UV – , P + red; primary squamules absent or inconspicuous. . . . *C. furcata*
   2. Squamules absent, even at the base; podetia yellowish green.
      Cortex dull and continuous; medulla UV – ; common. . . . *C. caroliniana*
      Cortex shiny and areolate (particularly in the distal portions); medulla UV + white; rare. . . . *C. uncialis*
1. Podetia simple, cup-like, proliferating, or absent, but never much-branched; always arising from persistent basal squamules.
   3. Podetia chronically absent or less than 4 mm long.
      4. Apothecia common, sessile or nearly so; squamules notably incised. . . . *C. caespiticia*
      4. Apothecia absent or uncommon, only sterile squamules present; squamules essentially entire or merely lobulate.
         5. Squamules yellowish-green, with a distinct yellowish cast beneath, P – .
            Squamules in flat open mats, C – beneath. . . . *C. robbinsii*
            Squamules in dense, rounded, subglobose mounds, C + green beneath. . . . *C. strepsilis*
         5. Squamules mineral grayish-green to brownish, white beneath, P + red (rarely yellow) or P – .
            6. Squamules K – , UV + bright white.
               Squamules P + yellow beneath, rare. . . . *C. atlantica*
               Squamules P – , common. . . . *C. squamosa*
            6. Squamules K + yellow or red beneath; UV – .

7. Squamules prevailingly less than 5 mm long, K+ yellow turning red beneath. . . . *C. polycarpoides*

7. Squamules mostly more than 5 mm long, K+ yellow or dingy beneath.
   Squamules P+ red beneath. . . . *C. apodocarpa*
   Squamules P− beneath. . . . *C. cariosa*

3. Podetia manifest, usually more than 4 mm long.

8. Podetia forming distinct cups.
   Apothecia and/or pycnidia brown; thallus greenish mineral gray; very common. . . . *C. chlorophaea*
   Apothecia and/or pycnidia red; thallus yellowish-green; uncommon. . . . *C. pleurota*

8. Podetia not forming distinct cups.

9. Podetia farinose-sorediate, unbranched, tapering to pointed tips.
   Squamules tiny, less than 1 mm long; pycnidia, if present, red; podetia P−. . . . *C. bacillaris*
   Squamules large, 2-5 mm long; pycnidia, if present, brown; podetia P+ red. . . . *C. coniocraea*

9. Podetia esorediate, branched or unbranched, usually tipped with apothecia.

10. Squamules very small, mostly less than 1 mm long; apothecia light brown or tan; podetial axis often appearing twisted. . . . *C. capitata*

10. Squamules mostly more than 1 mm long; apothecia dark brown or absent; podetial axis not twisted.
   Surface of podetia K−, distinctly squamulose, UV+ blue-white. . . . *C. squamosa*
   Surface of podetia K+ yellow turning red, nearly or quite without squamules, UV−. . . . *C. polycarpoides*

Cladonia apodocarpa Robb.

Squamules K+ yellow to dingy, C−, KC−, P+ red; without diaspores

Occasional on sandstone and mossy soil in well-drained upland forests. Typically the squamules are very large, often to 1 cm long, chalky white beneath, and with no podetia present. Ladd & Wilhelm 9486 MOR, which specimen contains norstictic acid as well as fumarprotocetraric acid and atranorin.

Another species known from the region, *C. clavulifera* Vain., is sometimes sterile but the squamules react K− and are generally much smaller than those of *C. apodocarpa*. See discussion under *C. polycarpoides*.

Cladonia atlantica Evans

Squamules K−, C−, KC−, P+ yellow; without diaspores

Known only from shaded mossy sandstone along Degognia Creek. Ladd & Wilhelm 9494 MOR.

Cladonia bacillaris (Ach.) Nyl.

Squamules K− or K+ dingy, C−, KC−, P− or P+ yellowish; podetia covered with farinose soredia

Occasional on logs and stumps in upland forests; rarely on lightly shaded sandstone. Ladd & Wilhelm 9488 MOR.

A similar species, *C. pityrea* (Flk.) Fr., with a P+ red reaction, occurs on decorticate logs in the region and should be sought in Jackson County; see also the comments under *C. coniocraea*.

Skorepa (1966) reported *C. decorticata* (Flk.) Spreng. from Jackson County but no Jackson County specimens could be located, nor is it cited in his dissertation (1973). It differs from *C. bacillaris* in having brown pycnidia.

Cladonia caespiticia (Pers.) Flk.

Squamules K−, C−, KC−, P+ red; without diaspores

Rare on logs and mossy, well-drained soil in upland forests. The brown apothecia are sessile on the squamules or minutely stipitate on short podetia. Hatcher 1284s SIU.

Cladonia capitata (Michx.) Spreng.

Podetia K− (or K+ dingy brown), C−, KC−, P+ red; without diaspores

Common on well-drained soils, sandstone, tree bases, and decorticate logs. This species has the smallest squamules of any *Cladonia* in the region, and is easily recognized by the furrowed, often twisted podetia. Skorepa's (1966) report of *C. caespiticia* (Skorepa 1133 SIU) should be referred here. Wilhelm 8310 MOR.

Cladonia cariosa (Ach.) Spreng.

Squamules K+ yellow, C−, KC−, P+ yellow; without diaspores

Rare; known only from a single collection made at Fountain Bluff. Ladd s.n., 17 March, 1976 MOR.

Cladonia caroliniana (Schwein.) Tuck.

Podetia K−, C−, KC−, P−; without diaspores

Frequent on exposed, xeric, sandstone ledges. Skorepa 1154 SIU.

Cladonia chlorophaea (Flk.) Spreng.

Podetia K− or K+ yellowish, C−, KC−, P− or P+ red; sorediate

Very common on rocks, dry sandy soil, mossy tree bases, and shaded decorticate logs in upland forests; also on sandy and clay soils in old worn out fields and eroded ditch banks. Skorepa's (1966 & 1973) reports of *C. verticillata* (Skorepa 1064 SIU) should be referred here. Wilhelm 8327 MOR.

This species includes several morphologies which in their extremes seem different from one another. In southern Illinois and Missouri material, however, these extremes are linked by specimens exhibiting an apparent continuum of gradations to the point where making consistent distinctions between the elements becomes impractical if not impossible. In Jackson County there are two chemical segregates: *C. cryptochlorophaea* Asah. (cryptochlorophaeic acid, with or without atranorin) and *C. grayi* Merr. ex Sandst. (grayanic acid), the latter of which is the common element. Both segregates are represented by forms with and without fumarprotocetraric acid. *C. chlorophaea*, in a strict sense, yet unknown from Jackson County, contains only fumarprotocetraric acid.

An esorediate species with cortical patches on the podetia, *C. pyxidata* (L.) Hoffm., itself perhaps not fully distinct from *C. chlorophaea*, occurs very rarely in the region and might be sought in Jackson County. If the apothecia or pycnidia are overlooked or absent, *C. pleurota* might key here. It is usually KC+ yellow and contains usnic acid.

Cladonia coniocraea (Flk.) Spreng.

Podetia K− or K+ dingy yellowish brown, C−, KC−, P+ red; sorediate

Uncommon on shaded sandstone, mosses over sandstone, and decorticate logs.

This species is characterized by the slenderly conic podetia arising from the surface of large squamules. Wilhelm 8412 MOR.

Another species, *C. cylindrica* (Evans) Evans, is known from the region and may occur in Jackson County. It differs from *C. coniocraea* in having much smaller, incised basal squamules and in possessing grayanic acid. Another species, *C. pityrea* (Flk.) Fr., is known from the region and differs from *C. coniocraea* in having podetia with granular soredia and smaller, incised primary squamules.

Cladonia cristatella Tuck.

> Podetia K−, C−, KC−, or KC+ yellowish, P+ yellow; without diaspores

Frequent on decorticate logs and sandy soil in dry upland forests and old fields; rarely on sandstone. Wilhelm 8316 MOR.

Cladonia furcata (Huds.) Schrad.

> Podetia K−, C−, KC−, P+ red; without diaspores

Common on shaded to exposed, moist or dry sandstone, and on slopes in dry upland forests. This species, which in most respects looks like a reindeer moss (*Cladina*), is easily identified by its scattered podetial squamules. It often forms extensive mats with *Cladina subtenuis*. Wilhelm 8325 MOR.

Cladonia piedmontensis Merr.

> Podetia K−, C−, KC−, or KC+ faint yellowish, P−; without diaspores

Uncommon on lightly shaded, mossy, sandstone ledges and outcrops. Ladd & Wilhelm 9500 MOR.

Although almost always found with podetia, in the sterile state this species could be confused with *C. robbinsii*, but the latter species has much larger squamules, sometimes 1 cm or more long.

Cladonia pleurota (Flk.) Schaer.

> Podetia K−, C−, KC+ yellowish, P−; sorediate

Known only on the basis of a poor specimen collected on soil beneath shrubs at the edge of a sandstone bluff. Hatcher 1392s SIU.

Cladonia polycarpoides Nyl.

> Podetia K+ yellow turning red, C−, KC−, P+ yellow to orange; without diaspores

Frequent on road and ditch banks, and on well-drained rocky soil in upland forest and in old fields. Including *C. symphycarpa* (Ach.) Fr. (Skorepa, 1966) and *C. subcariosa* Nyl. of Skorepa (1966 & 1973). Wilhelm 8326 MOR.

A similar species, *C. clavulifera* Vain., has been cited from the county by Skorepa (1966) and Stotler (1976), but we have been unable to locate specimens. It differs from *C. polycarpoides* in having a K− podetial reaction.

Cladonia robbinsii Evans

> Squamules K−, C−, KC−, or KC+ faint yellow, P−; without diaspores

Occasional on sandstone or among mosses over sandstone; usually in light shade. See also the discussion under *C. piedmontensis*. Wilhelm 11945 MOR.

Cladonia squamosa (Scop.) Hoffm.

Podetia K – , C – , KC – , P – , UV + blue-white; without diaspores

Locally frequent on dry or moist sandstone ledges and on mossy sandstone outcrops; often in light shade. Wilhelm 8384 MOR.

Cladonia strepsilis (Ach.) Vain.

Squamules K – , C + green, P + yellow; without diaspores

Uncommon on xeric sandstone exposures. This species usually occurs as compact subglobose mounds of squamules. Ladd & Wilhelm 9489 MOR.

Cladonia uncialis (L.) Wigg.

Podetia K – , C – , KC – , P – , medulla UV + bright white; without diaspores

Rare; among mosses over sandstone. Hatcher 1363s SIU.

Collema Wigg.

1. Thallus saxicolous. . . . *C. flaccidum*
1. Thallus corticolous.
   2. Thallus lobes narrow and linear, less than 1 mm wide; apothecia abundant; isidia absent (although upper surface may appear quite warty and pustulate). . . . *C. conglomeratum*
   2. Thallus lobes broad and rounded, 2-5 mm wide; apothecia absent; isidia present.
      Surface of lobes pustulate and ridged, dull olive-brown. . . . *C. furfuraceum*
      Surface of lobes flat and sublustrous, blackish-brown. . . . *C. subflaccidum*

Collema conglomeratum Hoffm.

Thallus K – , C – , KC – , P – ; without diaspores

Uncommon on exposed trunks and branches of post oaks and white oaks; often associated with *Dermatocarpon tuckermanii*. The small apothecia are usually abundant, often obscuring the thallus. Ladd & Wilhelm 9497 MOR.

Collema flaccidum (Ach.) Ach.

Thallus K – , C – , KC – , P – ; isidiate

Frequent on shaded, often moist sandstone and mosses over sandstone. Ladd & Wilhelm 9487 MOR.

Collema furfuraceum (Arn.) Du Rietz

Thallus K – , C – , KC – , P – ; isidiate

Common on shaded trunks of deciduous trees and cedars. Morphologically this species is essentially indistinguishable from its saxicolous relative, *C. flaccidum*. Wilhelm 8459 MOR.

Collema subflaccidum Degel.

Thallus K – , C – , KC – , P – ; isidiate

Occasional on shaded trunks of deciduous trees in upland forests. = *C. subfurvum* (Muell. Arg.) Degel. Wilhelm 8459a MOR.

Dermatocarpon Eschw.

1. Thallus corticolous on deciduous trees in upland forests, densely rhizinate. . . . *D. tuckermanii*
1. Thallus saxicolous or terricolous, with or without rhizines.

   Thallus rhizinate, of small, closely adnate squamules on calcareous or arenaceous soils; uncommon. . . . *D. lachneum*

   Thallus, without rhizines, umbilicate to loosely squamulose on rock; common.. . . *D. miniatum*

Dermatocarpon lachneum (Ach.) A.L. Sm.

Cortex K – ; without diaspores
Medulla K – , C – , KC – , P –

Characteristic of thin soil pockets on exposed limestone ledges, habitats which are rare in Jackson County. Including *D. hepaticum* (Ach.) Th. Fr. Wilhelm 8432 MOR.

Dermatocarpon miniatum (L.) Mann

Cortex K – , without diaspores
Medulla K – , C – , KC – , P –

A common and characteristic species of shaded or exposed, moist or dry, sandstone and limestone ledges, cliffs, walls, and beds of temporary streams. Wilhelm 8322 MOR.

A closely related species, *D. fluviatile* (G. Web.) Th. Fr. has a thallus which is less umbilicate and turns bright green when wet. Skorepa (1966) cited his #1855, as *D. aquaticum* (Weiss) Zahlbr., from Degognia Hollow, but we could not locate the specimen and it was not cited in his dissertation. Skorepa (1973) reports that *D. miniatum* occurs in two growth forms, with those from carbonate substrates tending to be umbilicate, while those from sandstone more often form irregular squamulose rosettes which he says resemble *D. fluviatile*.

Dermatocarpon tuckermanii (Rav.) Zahlbr.

Cortex K – , without diaspores
Medulla K – , C – , KC – , P –

Uncommon on exposed to lightly shaded trunks of deciduous trees in open upland forests, especially post oak and white oak, often growing with *Collema conglomeratum*. Skorepa (1973) mentions having seen this species on dolomite in Tennessee, and we see it regularly on dry carbonate rock in Missouri. Wilhelm 8317 MOR.

Dirinaria (Tuck.) Clem.

Dirinaria frostii (Tuck.) Hale & W. Culb.

Cortex K + yellow; sorediate
Medulla K – , C – , KC – , P –

Uncommon on lightly shaded dry sandstone, usually on vertical faces protected by overhanging ledges. Hale & Culberson (1970) credit Hale & W. Culberson with having placed this species into *Dirinaria*, though Hale (1969 & 1979) credits the combination to Awasthi. Wilson 2664 SIU.

Heterodermia Trev.

1. Lower surface ecorticate and fibrous, tinted with orange, the tinted zones K + purple. . . . *H. obscurata*

1. Lower surface corticate and smooth, white to tan, not K + purple.

   Soralia strongly crescent-shaped on the margins of the lobe tips; medulla K + yellow; rhizines projecting beyond the lobe margins. . . . *H. speciosa*

   Soralia nearly or quite continuous along the lobes and creases of the thallus; medulla K + yellow turning red; rhizines not projecting beyond the lobe margins. . . . *H. albicans*

Heterodermia albicans (Pers.) Swinsc. & Krog

Cortex K + yellow; sorediate
Medulla K + yellow turning red, C − , KC − , P + yellow-orange

Uncommon on trunks of deciduous trees. Local reports of *H. domingensis* (Ach.) Trev. probably should be referred here. = *Anaptychia revenelii* (Tuck.) Zahlbr. Skorepa 4002 SIU.

Heterodermia obscurata (Nyl.) Trev.

Cortex K + yellow, the lower surface K + purple where pigmented; sorediate
Medulla K + yellow, C − , KC − , P + yellow

Occasional on bark of deciduous trees in upland forests. = *Anaptychia obscurata* (Nyl.) Vain. Hatcher 970s SIU.

Heterodermia speciosa (Wulf.) Trev.

Cortex K + yellow; sorediate
Medulla K + yellow, C − , KC − , P + yellow

Common on trunks and branches of deciduous trees in open forests; also on sandstone and among mosses over sandstone. = *Anaptychia speciosa* (Wulf.) Mass., = *Heterodermia tremulans* (Muell. Arg.) W. Culb. of Skorepa (1973). Wilhelm 8377 MOR.

Hypotrachyna (Vain.) Hale

Hypotrachyna livida (Tayl.) Hale

Cortex K + yellow; without diaspores
Medulla K − , C − , KC + rose, P −

On upper branches of canopy trees in upland forests; frequent but seldom collected. = *Parmelia livida* Tayl. Wilhelm 8376 MOR.

Lecanora Ach.

Lecanora muralis (Schreb.) Ach.

Cortex K − ; without diaspores
Medulla K − , C − , KC − , P −

Known only from exposed sandstone boulders in a pasture near Cora. Ladd 9502 MOR.

A similar species, *Dimelaena oreina* (Ach.) Norm., is known from the region and might be sought in Jackson County. It differs in having a medulla which reacts C + red, and may be spotted in the field by the black apothecial disks; the disks of *Lecanora muralis* are yellowish-tan to brown.

Leptogium S. Gray

1. Lobes flat, the surfaces shiny, without wrinkles.
   2. Lobes finely coralloid-branched; thallus without isidia. . . . *L. tenuissimum*
   2. Lobes without coralloid branches; thallus isidiate.
      Thallus olive-brown; lobes about 1-2 mm wide; apothecia common. . . . *L. dactylinum*
      Thallus slate-gray; lobes usually 3-4 mm wide; apothecia very rare. . . . *L. cyanescens*
1. Lobes usually more or less convoluted; surfaces shiny or dull, manifestly wrinkled.
   3. Lobes finely dissected into slender isidioid or fimbriate segments. . . . *L. lichenoides*
   3. Lobes blunt and rounded, the surfaces often finely isidiate.
      Lobes coarsely foveolate-wrinkled into strong ridges and furrows; thallus brownish-gray. . . . *L. milligranum*
      Lobes finely reticulate-wrinkled; thallus slate-gray. . . . *L. austroamericanum*

Leptogium austroamericanum (Malme) Dodge

Thallus K – , C – , KC – , P – ; isidiate

Frequent on lower trunks and bases of deciduous trees in open forests; rarely on shaded mossy rocks. Wilhelm 8458 MOR.

Leptogium cyanescens (Ach.) Koerb.

Thallus K – , C – , KC – , P – ; isidiate

Common on shaded, moist, bare or mossy sandstone, and on shaded lower trunks of deciduous trees. Wilhelm 8321 MOR.

Leptogium dactylinum Tuck.

Thallus K – , C – , KC – , P – ; isidiate

Known locally only from a shaded mossy tree trunk, though throughout the region this is typically a species of shaded, often mossy carbonate rocks. Wilhelm 8425 MOR.

Leptogium lichenoides (L.) Zahlbr.

Thallus K – , C – , KC – , P – ; isidiate by lobular dissection

Occasional among mosses over rock in moist shaded sites. The thallus often blends with the moss cushion and is easily overlooked. Ladd & Wilhelm 9485 MOR.

Leptogium milligranum Sierk

Thallus K – , C – , KC – , P – ; isidiate

Occasional on trunks of deciduous trees and cedars in open forests and along roadsides and fencerows. Hale (1969 & 1979) spello the epithet "millegranum". Skorepa 823 SIU.

Leptogium tenuissimum (Dicks.) Fr.

Thallus K – , C – , KC – , P – ; isidiate by coralloid branching

Included here solely on the basis of the report by Skorepa (1973), who cites his #3872 from Little Grand Canyon; he recorded it from the bases of white oaks and on moss in dry upland woods.

Parmelia Ach.

1. Thallus beset with simple to coralloid isidia. . . . *P. rudecta*
1. Thallus without isidia, though sometimes densely lobulate.
   Thallus sorediate. . . . *P. subrudecta*
   Thallus without soredia. . . . *P. hypoleucites*

Parmelia hypoleucites Nyl.

Cortex K+ yellow; without diaspores
Medulla K−, C+ red, KC+ red, P−

Uncommon on sandstone walls and ledges; rarely on trunks of deciduous trees. Ladd s.n., 3.Mar.76 MOR.

A morphologically similar species with a C− medullary reaction, *P. bolliana* Muell. Arg., is known from corticolous substrates in the region.

Parmelia rudecta Ach.

Cortex K+ yellow; isidiate
Medulla K−, C+ red, KC+ red, P−

Abundant on trees and rocks in open or shaded situations throughout the county. This is one of the most common and widely distributed macrolichens in the county. Wilhelm 8318 MOR.

Parmelia subrudecta Nyl.

Cortex K+ yellow; sorediate
Medulla K−, C+ red, KC+ red, P−

Frequent on deciduous trees in open forests; rarely on shaded sandstone. This species is seldom collected, perhaps because of its resemblance to the ubiquitous *P. rudecta*. Wilhelm 8300 MOR.

Parmelina Hale

1. Thallus without soredia or isidia; apothecia common. . . . *P. galbina*
1. Thallus isidiate or sorediate; apothecia very rare.
   Thallus isidiate, lobes about 1 mm wide; tightly adnate on siliceous rocks. . . . *P. obsessa*
   Thallus sorediate, lobes 2 mm or more wide; rather loosely adnate on trees and rocks. . . . *P. aurulenta*

Parmelina aurulenta (Tuck.) Hale

Cortex K+ yellow; sorediate
Medulla K− or K+ yellow, C−, KC−, P−

Common on open and shaded deciduous trees and cedars; also on shaded rocks. = *Parmelia aurulenta* Tuck. Wilhelm 8364 MOR.

Parmelina galbina (Ach.) Hale

Cortex K+ yellow; without diaspores
Medulla K+ yellow turning red or darkening; C−, KC−, P+ orange

Frequent on limbs and upper trunks of deciduous trees in upland forests. = *Parmelia galbina* Ach. Wilhelm 8428 MOR.

Parmelina obsessa (Ach.) Hale

Cortex K + yellow; isidiate
Medulla K + deeper yellow, C − , KC − , P + orange

Locally frequent on lightly shaded sandstone boulders and ledges. = *Parmelia obsessa* Ach. Ladd & Wilhelm 9484 MOR.

Parmotrema Mass.

1. Thallus yellowish-green, isidiate; saxicolous. . . . *P. madagascariaceum*
1. Thallus mineral gray, without isidia; corticolous or saxicolous.
   2. Soredia absent.
      Medulla K + yellow turning red. . . . *P. eurysacum*
      Medulla K − . . . . *P. michauxianum*
   2. Soredia present.
      Lower surface with a white or light tan rhizine-free zone near the margins; norstictic acid present. . . . *P. hypotropum*
      Lower surface black or dark brown, and more or less rhizinate to the margins; salazinic acid present. . . . *P. reticulatum*

Parmotrema eurysacum (Hue) Hale

Cortex K + yellow; without diaspores
Medulla K + yellow turning red, C − , KC − , P + orange

Known only from a single collection from the trunk of a bluff top cedar tree. This collection was originally cited as *P. michauxianum* (Zahlbr.) Hale (Skorepa 1966). Not treated by Hale (1969). Skorepa 460 SIU.

Another species known from the region, *P. perforatum* (Jacq.) Mass., would key here but differs in that there is a broad bare white zone along the lower margin of the thallus, and the thallus is very loosely adnate to suberect.

Parmotrema hypotropum (Nyl.) Hale

Cortex K + yellow; sorediate
Medulla K + yellow turning red, C − , KC − , P + orange

Common on trunks and limbs of mature trees, and on lightly shaded ledges and boulders in dry upland forests. = *Parmelia hypotropa* Nyl. Wilhelm 8343 MOR.

Skorepa (1973) indicates that all his specimens of *Parmotrema hypotropum* from southern Illinois contain stictic acid, a datum which, if true, would imply that all southern Illinois material is referable to *P. hypoleucinum* (B. Stein) Hale. This observation is at variance with our own. All of our Jackson County specimens contain only norstictic acid. We do have *P. hypoleucinum* from the region, but it apparently is uncommon.

Parmotrema madagascariaceum (Hue) Hale

Cortex K + yellow; isidiate
Medulla K − , C − or C + rose, KC + rose, P −

Uncommon on shaded or exposed vertical sandstone, often on canyon walls. This species superficially resembles a *Xanthoparmelia*, but is easily distinguished by the prominent marginal cilia. = *Parmelia madagascariacea* (Hue) Abb. Wilhelm 8379 MOR.

All of the Jackson County specimens, and most material from the region, react C − , KC + rose in the medulla. Hale (1965 & 1979) included all C-specimens in

Parmelia xanthina (Muell.Arg.) Vain. According to Almeda & Dey (1973), specimens reacting KC + rose (gyrophoric acid) should display a C + "very faint pink, fast-fading" medullary reaction and should be included in *P. madagascariacea* (Hue) Abb. In the Jackson County material the reaction is so ephemeral as to be all but undetectable; nevertheless, gyrophoric acid is present in the Jackson County specimen and in others we have from the region. Of the two species, Skorepa (1973) recorded only *P. madagascariacea* from southern Illinois.

Parmotrema subtinctorium (Zahlbr.) Hale, an inconspicuously ciliate, mineral gray, isidiate species, is occasional on lightly shaded deciduous trees in the region and should be sought in Jackson County.

Parmotrema michauxianum (Zahlbr.) Hale

Cortex K + yellow; without diaspores
Medulla K − , C − , KC + rose, P + red

While this species is occasional elsewhere in the region, it is included here solely on the basis of the reports by Skorepa (1973 & 1977) who cites his #6425 from Devil's Den. It is occasional on deciduous trees in upland woods.

Parmotrema reticulatum (Tayl.) Choisy

Cortex K + yellow; sorediate
Medulla K + yellow turning red, C − , KC − , P + orange or red

Occasional on bark of deciduous trees and lightly shaded sandstone in upland forests. = *Parmelia reticulata* Tayl. Hatcher 1288s SIU.

Peltigera Willd.

Upper cortex dull to sublustrous, tomentose, at least on the lobes; lower surface with pale or darkening, distinct, narrow, raised veins; rhizines numerous. . . . *P. canina*
Upper cortex lustrous, smooth, without tomentum; lower surface with dark, indistinct, broadly flattened veins; rhizines few to absent. . . . *P. polydactyla*

Peltigera canina (L.) Willd.

Cortex K − ; without diaspores
Medulla K − , C − , KC − , P −

Frequent on thin soils over sandstone, often among mosses, as well as on humus and rocky soil on slopes in dry upland forests; occasionally in well-drained shaded mowed areas. Including *P. praetextata* (Somm.) Vain., which is called *P. canina* var. *rufescens* f. *innovans* (Koerb.) Thoms. by Thomson (1950), and is segregated by the "isidia" which develop on regenerated portions of torn thallus. Thomson refers most of the Illinois material to *P. canina* var. *rufescens* (Weiss) Mudd. Wilhelm 8324 MOR.

Peltigera polydactyla (Neck.) Hoffm.

Cortex K − ; without diaspores
Medulla K − , C − , KC − , P −

Known only from lightly shaded mossy soil over sandstone at the head of a small tributary canyon along Degognia Creek. Including *P. elisabethae* Gyel., which is called *P. polydactyla* f. *microphylla* Anders by Thomson (1950), and is segregated by the "isidia" which develop on regenerated portions of torn thallus. Ladd & Wilhelm 9490 MOR.

Phaeophyscia Moberg

1. Medulla bright red or orange. . . . *P. rubropulchra*
1. Medulla white.
   2. Fine colorless hairs present on margins of upper cortex. . . . *P. cernohorskyi*
   2. Cortical hairs absent.
      3. Soredia absent; lobe margins with erect flattened isidioid lobules. . . . *P. imbricata*
      3. Soredia present; lobe margins without lobules.

         Soralia coarse and rather diffuse along the margins and over the surfaces of the lobes; saxicolous or rarely corticolous. . . . *P. adiastola*

         Soralia powdery, delimited, round and capitate, mostly at the ends of small lobes, corticolous. . . . *P. pusilloides*

Phaeophyscia adiastola (Essl.) Essl.

Cortex K – ; sorediate
Medulla K – , C – , KC – , P –

Common on moist to dry shaded rocks, often over mosses, and on mossy tree bases; rarely on trees in upland forests. Local reports of *Phaeophyscia orbicularis* (Neck.) Moberg [= *Physcia orbicularis* (Neck.) Poetsch.] either should be referred here or to *Phaeophyscia rubropulchra*. Wilhelm 8439 MOR.

Phaeophyscia cernohorskyi (Nadv.) Essl.

Cortex K – ; sorediate
Medulla K – , C – , KC – , P –

Uncommon on exposed tree trunks in fields, fencerows, and along forest edges. Not treated by Hale (1969). Ladd & Wilhelm 9498 MOR.

An esorediate species with colorless cortical hairs on the margins of the apothecia, *P. hirtella* Essl., is frequent in the area and should be sought in Jackson County.

Phaeophyscia imbricata (Vain.) Essl.

Cortex K – ; thallus densely lobulate
Medulla K – , C – , KC – , P –

Occasional on shaded sandstone, among mosses over sandstone, and on mossy tree bases in upland forests. Because the lower surface of this species can be white towards the margins it may initially be mistaken for a *Physcia*, but the upper cortex is K – while that of most *Physcia* species is K + yellow. = *Physcia lacinulata* Muell.Arg. Ladd 9501 MOR.

Two other species of *Phaeophyscia* are quite common in the region and should be sought in Jackson County. Both *P. ciliata* (Hoffm.) Moberg and *P. hirtella* Essl. are esorediate corticolous species without copious marginal lobules. The latter two taxa are very similar morphologically, except that *P. hirtella* has numerous fine transparent cortical hairs on the lobe margins and apothecial rims.

Phaeophyscia pusilloides (Zahlbr.) Essl.

Cortex K – ; sorediate
Medulla K – , C – , KC – , P –

While this species is fairly common northward and westward, it apparently is quite rare in Jackson County. Not treated by Hale (1969). Skorepa 1001 SIU.

A similar species, *Physciopsis adglutinata* (Flk.) Choisy, (= *Physcia elaeina* of Skorepa, 1973) occurs in the region and differs in being smaller, very tightly appressed to the substrate, and without rhizines.

Phaeophyscia rubropulchra (Degel.) Moberg

Cortex K − ; sorediate
Medulla K + dark purple, C − , KC − , P −

Frequent on the lower and mid-trunks of deciduous trees in all types of forest; also on shaded rocks and among mosses over rocks. = *Physcia orbicularis* (Neck.) Poetsch. of Hale (1969), in part. Ladd 9505 MOR.

Physcia (Schreb.) DC.

1. Thallus without soredia (or isidia).
   2. Medulla K − . . . . *P. stellaris*
   2. Medulla K + yellow.
      Thallus saxicolous; lobes tending to be longer than wide. . . . *P. phaea*
      Thallus corticolous; lobes about as wide as long. . . . *P. aipolia*
1. Thallus sorediate.
   3. Lobes very finely branched or divided, less than 0.5 mm wide; soredia more or less granular.
      Thallus usually corticolous; soredia somewhat erect and appearing lobulate; medulla K − . . . . . *P. millegrana*
      Thallus saxicolous; soredia granular; medulla K + yellow. . . . *P. subtilis*
   3. Lobes narrow but not finely divided, usually more than 0.5 mm wide; soredia powdery.
      Soredia in laminal soralia; cortex K + yellow. . . . *P. americana*
      Soredia marginal on the lobe tips; cortex K − . . . . *P. chloantha*

Physcia aipolia (Ehrh.) Hampe

Cortex K + yellow; without diaspores
Medulla K + yellow, C − , KC − , P + yellow

Uncommon on exposed deciduous trees in fields, along fence rows, and in small towns. Some specimens of *P. stellaris* might key here if care is not taken, when applying the medullary spot test, to be certain that it is indeed atranorin from the medulla which has provided the positive yellow reaction and not atranorin bleeding over from the cortex into the exposed medulla test site. Hatcher 1258s SIU.

Another species known from the area, *P. alba* (Fee) Muell.Arg., is much smaller, with lobes scarcely 1 mm wide, but otherwise morphologically similar to *P. aipolia*.

Physcia americana Merr.

Cortex K + yellow; sorediate
Medulla K + yellow, C − , KC − , P + yellow

Common on trees in upland forests, as well as on lightly shaded sandstone ledges and boulders. = *Physcia tribacoides* Nyl. Wilhelm 8375 MOR.

Physcia chloantha Ach.

Cortex K − ; sorediate
Medulla K − , C − , KC − , P −

Uncommon on deciduous trees and cedars. Not treated by Hale (1969). Hatcher 1277s SIU.

This species might be confused with *Phaeophyscia pusilloides*, but the latter has capitate rather than hooded, crescent-shaped soralia, lobes mostly less than 1 mm wide, and a black undersurface. See also the comments regarding *Physciopsis adglutinata* under *Phaeophyscia pusilloides*.

Physcia millegrana Degel.

Cortex K + yellow; sorediate
Medulla K −, C −, KC −, P −

Common on shaded to exposed bark and wood, particularly in residential areas, small towns, along roadsides, in floodplains, and on old wood fence posts; uncommon in natural communities. This species also occurs rarely on shaded sandstone. Wilhelm 8335 MOR.

Physcia phaea (Tuck.) Thoms.

Cortex K + yellow; without diaspores
Medulla K + yellow, C −, KC −, P + yellow

Rare on sandstone along creeks in upland forests. Skorepa 4800 SIU.

Also in the region, *P. halei* Thoms. has much narrower lobes (less than 0.5 mm wide) than *P. phaea*; both grow on siliceous rocks. *P. subtilis* would key here if the granular soredia are overlooked.

Physcia stellaris (L.) Nyl.

Cortex K + yellow; without diaspores
Medulla K −, C −, KC −, P −

Common on limbs and exposed trunks of trees in old fields, upland forests, along roadsides, and even in small towns. Wilhelm 8338 MOR.

Physcia subtilis Degel.

Cortex K + yellow; sorediate
Medulla K + yellow, C −, KC −, P + yellow

Locally frequent on exposed to lightly shaded sandstone boulders and ledges. Wilhelm 8378 MOR.

Physciopsis Choisy

Physciopsis syncolla (Tuck.) Poelt

Cortex K −; without diaspores
Medulla K −, C −, KC −, P −

While this species is frequent elsewhere in the region, it is included here solely on the basis of the report by Skorepa (1973), who cites his #6529 from Grand Tower. It is particularly frequent on elms, cottonwoods, and hickories, along streams, in disturbed open woods, or in residential areas.

A similar species, *Physciopsis adglutinata* (Flk.) Choisy, [= *Physcia elaeina* of Skorepa (1973)] is frequent in the region and differs in having small laminal soralia. See also the comments under *Phaeophyscia pusilloides*.

Physconia Poelt

Physconia detersa (Nyl.) Poelt

Cortex K −; sorediate
Medulla K −, C −, KC −, P −

Occasional on trees, rocks, and mosses over rocks. = *Physcia grisea* (Lam.) Zahlbr. Wilhelm 8315 MOR.

Placynthium S. Gray

Placynthium nigrum (Huds.) S. Gray

Thallus K−, C−, KC−, P−; isidiate

On exposed limestone; known only from Devil's Bake Oven south of Grand Tower and from an outcrop along Kinkaid Creek. Not treated by Hale (1969). Skorepa 4110 SIU.

Pseudoparmelia Lynge

1. Thallus mineral gray, the lobe surfaces reticulate-ridged. . . . *P. crozalsiana*
1. Thallus yellowish-green, the lobe surfaces not distinctly ridged.
   Thallus evidently sorediate with fully open soredia; without gyrophoric acid; typically corticolous. . . . *P. caperata*
   Thallus with large pustular isidia or appearing coarsely incipiently sorediate; with or without gyrophoric acid; almost always saxicolous, at least locally. . . . *P. baltimorensis*

Pseudoparmelia baltimorensis (Gyel. & For.) Hale

Cortex K−; isidiate
Medulla K−, C− or C+ red, KC− or KC+ rose, P+ red

Characteristic on sandstone ledges and boulders in light to moderate shade; more rarely on the bases of deciduous trees in upland forests. Many of our local specimens contain gyrophoric acid, but even in these specimens positive reagent tests can be hard to obtain. The coarse pustular isidia separate this species from members of the genus *Xanthoparmelia* with which it often grows. = *Parmelia caperata* (L.) Hale, in part, of Hale (1969). Wilhelm 8323 MOR.

Pseudoparmelia caperata (L.) Hale

Cortex K−; sorediate
Medulla K−, C−, KC−, P+ red

Common on tree trunks and branches in upland forests, along roadsides, and even in small towns; more rarely on sandstone. = *Parmelia caperata* (L.) Ach., in part, of Hale (1969). Wilhelm 8301 MOR.

Pseudoparmelia crozalsiana (B. de Lesd. ex Harm.) Hale

Cortex K+ yellow; sorediate
Medulla K+ yellow, C−, KC−, P+ orange

Locally frequent on deciduous trees and cedars in upland forests and along country roadsides. = *Parmelia crozalsiana* B. de Lesd. ex Harm. Wilhelm 8441 MOR.

Pyxine Fr.

Soredia laminal in round soralia; lobes typically with a conspicuous patch of dense pruina just in front of the tips; medulla yellow; cortex K− and UV+ bright yellow. . . . *P. caesiopruinosa*
Soredia in laminal and marginal soralia; lobes without pruina or with a diffuse patch near the tips; medulla salmon-orange; cortex K+ yellow and UV−. . . . *P. sorediata*

Pyxine caesiopruinosa (Nyl.) Imsh.

Cortex K−, UV+ bright yellow; sorediate
Medulla K−, C−, KC−, P−

Common on trees in upland forest, along roadsides and streams, and in residential areas and small towns; rarely on shaded sandstone. Wilson 2673 SIU.

Pyxine sorediata (Ach.) Mont.

Cortex K + yellow; sorediate
Medulla K − (or darkening), C − , (or darkening), KC − , P −

Frequent on lower and mid-trunks of trees in upland forests and along country roadsides; occasionally on shaded sandstone. Wilhelm 8442 MOR.

Ramalina Ach.

Ramalina intermedia Nyl.

Cortex K − ; sorediate
Medulla K − , C − , KC − , P −

Rare on shaded vertical sandstone. Wilson 2548 SIU.

Another species known from the region, *R. americana* Hale, lacks soredia (and isidia) and grows on trees.

Usnea P. Br. ex Adans.

Soredia and isidia absent; apothecia often present. . . . *U. strigosa*
Soredia or isidia present; apothecia absent. . . . *U. mutabilis*

Usnea mutabilis Stirt.

Cortex K − ; isidiate/sorediate
Medulla K − , C − , KC − , P −

Known locally only from a collection made on vertical sandstone in an upland forest. Elsewhere in the area, however, this species more typically is found on corticolous substrates. Stotler 1686 SIU.

Another sorediate species, *U. herrei* Hale, has a white medulla, rather than red as is *U. mutabilis*; the medulla of the former reacts K + yellow turning red. It is known from the region and might be sought in Jackson County. Rare in the region of *U. rubicunda* Stirt., with a reddish cortex on the older portions of the thallus and a medulla which reacts K + yellow.

Usnea strigosa (Ach.) Eat.

Cortex K − ; without diaspores (although sometimes densely fibrillose)
Medulla K − or K + red, C − , KC − , P + yellow or orange

Uncommon on trees and shaded sandstone in upland forests. Wilson 2662 SIU.

Xanthoparmelia (Vain.) Hale

1. Thallus isidiate.
   Lower surface tan to light brown. . . . *X. plittii*
   Lower surface black or essentially so. . . . *X. conspersa*
1. Thallus without isidia.
   2. Lower surface tan to light brown. . . . *X. cumberlandia*
   2. Lower surface black or essentially so.
      Stictic acid present. . . . *X. hypopsila*
      Salazinic acid present. . . . *X. tasmanica*

Xanthoparmelia conspersa (Ach.) Hale

Cortex K − ; isidiate
Medulla K + yellow turning red, C − , KC − , P + orange

Locally frequent on exposed to lightly shaded sandstone. = *Parmelia conspersa* (Ach.) Hale. Wilhelm 8381 MOR.

Xanthoparmelia cumberlandia (Gyel.) Hale

Cortex K − ; without diaspores
Medulla K + yellow turning red, C − , KC − , P + orange

Occasional on exposed to lightly shaded sandstone. = *Parmelia cumberlandia* (Gyel.) Hale. Wilhelm 8382a MOR.

Also known from the region, and probably in Jackson County, is *Xanthoparmelia taractica* (Kremplh.) Hale. It differs from *X. cumberlandia* in having salazinic acid instead of stictic acid.

Xanthoparmelia hypopsila (Muell.Arg.) Hale

Cortex K − ; without diaspores
Medulla K + yellow turning red, C − , KC − , P + orange

While this species is common in the region, our only Jackson County record is based upon the report by Skorepa (1973) who cites his #1702, from Little Grand Canyon. = *Parmelia hypopsila* Muell.Arg. Skorepa 961 SIU, cited in Skorepa (1966) as *Parmelia stenophylla* (Ach.) Heug., probably should be referred here, but we have not tested it for stictic acid.

Also known from the region is *Xanthoparmelia hypomelaena* (Hale) Hale. It is morphologically identical to *X. hypopsila*, but contains fumarprotocetraric acid instead of stictic and norstictic acids, and has a K − medulla.

Xanthoparmelia plittii (Gyel.) Hale

Cortex K − ; isidiate
Medulla K + yellow turning red, C − , KC − , P + orange

Uncommon on exposed or lightly shaded sandstone expanses. = *Parmelia plittii* Gyel. Wilhelm 8382 MOR.

Also frequent in the region, though as yet unknown from Jackson County, is *Xanthoparmelia subramigera* (Gyel.) Hale. It is morphologically identical to *X. plittii*, but has fumarprotocetraric acid instead of stictic and norstictic acids, and has a K − medulla.

Xanthoparmelia tasmanica (Hook. & Tayl.) Hale

Cortex K − , without diaspores
Medulla K + yellow turning red, C − , KC − , P + orange

Locally frequent on exposed or lightly shaded sandstone. = *Parmelia tasmanica* Hook. & Tayl. Wilhelm 8401 MOR.

Xanthoria (Fr.) Th. Fr.

Lobes narrow and dissected, about 0.5 mm wide; soredia in marginal or sublaminal soralia. . . . *X. candelaria*

Lobes broader and sparingly branched, fully 1 mm or more wide; soredia in more or less hooded soralia at the lobe tips. . . . *X. fallax*

Xanthoria candelaria (L.) Th. Fr.

Cortex K + purple; sorediate
Medulla K − , C − , KC − , P −

Common on exposed tree trunks and rocks, often in full sun. Wilhelm 8437 MOR.

Xanthoria fallax (Hepp) Arn.

Cortex K + purple; sorediate
Medulla K − , C − , KC − , P −

Uncommon on exposed trunks of deciduous trees. Although all of the Jackson County specimens are corticolous, this species also occurs on saxicolous substrates elsewhere in the region. Wilhelm 1043a MOR.

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TAXONOMY OF SOUTHERN ILLINOIS MEADOWLARKS

Key words: (*Sturnella magna* and *argutula*), meadowlark, Illinois, taxonomy.)

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ABSTRACT

Discriminant function analysis (DFA) of 358 meadowlark specimens, collected in southern Illinois between 1960 and 1967, determined that the population consisted of eastern meadowlarks (*Sturnella magna magna*), southern meadowlarks (*S.m. argutula*), and intermediate forms. A total of 16 scores and measurements, subsequently reduced to nine, were utilized, and resulted in separation of 88 male and 87 female *argutula* specimens from *magna* specimens. Sixty male specimens and eight female specimens reflected discriminant scores which positioned them as intermediate forms.

INTRODUCTION

Meadowlarks (genus *Sturnella*), found from Ontario to South America (Bent 1908; Chapman 1900; Saunders 1932; Stone 1897), have been the object of controversy among ornithologists since Audubon (1844) identified the western form, *Sturnella neglecta*, west of the Mississippi river. Our study sought to examine the meadowlark population in southern Illinois with regard to *S.m. magna* and *S.m. argutula*; we anticipated the presence of the southern meadowlark. As a result of interbreed-

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ing of the two forms, production of offspring exhibiting intergrade characteristics was suspected, if *argutula* was indeed present.

S.m. magna is found from eastern Minnesota, southern Ontario, Quebec and New Brunswick, south to central Texas, South Carolina and Missouri, west to Nebraska, central Kansas and the 100th meridian in Oklahoma, and northern Texas (Saunders 1932:67). Beal (1895) described the range of *S. magna* as extending from the eastern United States and ranging as far west as the Great Plains. Chapman (1900:297) listed this form as observed throughout the United States east of the 100th meridian, with the exception of southern Florida. *S.m. argutula* is resident from Louisiana and southeastern Texas east to Florida; northward in the Mississippi Valley to southeastern Indiana. It is also found along the Atlantic Coast as far north as Georgia and perhaps to southern South Carolina (Saunders 1932). Chapman (1900) simply listed the range of the southern meadowlark as southern Florida.

The eastern meadowlark was described as conspicuous and abundant in Illinois by Ridgway (1873:200). Forbes and Gross (1923) listed *magna* as a permanent southern Illinois resident. From March to mid-December the eastern form was reported as common to abundant by Kleen and Bush (1971). Stone (1897) listed the southern meadowlark for southern Illinois and Indiana. Ridgway (1902) described breeding birds from southern Illinois as more closely resembling birds from the southern U.S. than those from New England.

Southern Illinois was recorded as part of the range of *argutula* in the 12th supplement to the A.O.U. checklist (1903). Specimens of the southern race were collected in southern Illinois in 1897 (Cory 1909) and Howell (1910) said it was common in southern Illinois. Saunders (1932) reported the southern form as occurring in southeastern Indiana and southern Illinois.

METHODS

Roseberry and Klimstra (1970) studied the nesting ecology and reproduction of the eastern meadowlark between 1960 and 1967. Their research yielded the 358 specimens utilized in this study, of which 149 were females and 209 were males. Table 1 lists the numbers of male and female specimens collected, by month of the year. The sample composition was rather evenly distributed among breeding and wintering birds.

Taxonomic characterizations utilized in our study were based primarily upon Saunders (1932). The series of scores and measurements employed included the following: (1) FWL (folded wing length), or chord of the wing, measured to the tip of the longest primary; (2) TMT (tarsometatarsal length), measured from the lower edge of the last complete scute to the hollow formed at the tibio-tarso-metatarsal joint; (3) RAT (ratio of leg length to wing length); (4) LOC (length of exposed culmen); (5) TRL (length of tail rectrices), measured from the tip of the longest central tail rectrix to the point of insertion at the skin; (6) HCL (hind claw length), measured from the lower edge of scutellation to the ankle joint. Rohwer (1972) suggested the use of additional taxonomic characteristics as follows: (7) TBN (thickness of the black notch, or vee), measured at the center of the breast; (8) LYL (lore yellow length), the length of yellow feather coloration on the mallar region immediately above the submallar apterium; (9) LYH (lore yellow height), the height of yellow feather coloration in the mallar region above the submallar apterium; (10) R3, the extent of white feather coloration bordering the rachis of the inner vane of tail rec-

trix 3; (11) R4, same as for R3, for tail rectrix 4; (12) R5, same as for R3, for tail rectrix 5; (13) R6, same as for R3, for tail rectrix 6. Character (14), CRS (central rectrix score), was adapted from Rohwer (1972:310), and Szijj (1963:180), and used to code the distribution of black barring in the central tail rectrices of both sexes (Figure 1a). Character (15), YCS (yellow cheek score), was derived from Szijj (1963), and reflected the degree of yellow coloration of the sides of the cheek region with respect to a line extending from the base of the mandibles down the sides of the neck (Figure 1b). Character (16), BFS (back feather score), also adaped from Szijj (1963), was derived from feather marking patterns from the center of the back area (Figure 1c). All measurements reflected standardized methods (Baldwin et al. 1931) and were taken with dial calipers. Measurements 1 through 6 were recorded to the nearest .01 mm., while 7 through 13 were to the nearest .1 mm.

Data were summarized by utilization of discriminant function analysis (DFA) (Fisher 1936); this method was employed by Rohwer (1971, 1972, 1973) and Szijj (1963) on meadowlarks. Reference specimens, obtained from the American Museum of Natural History, consisted of 15 male and 15 female *magna* and an equal number of male and female *argutula*. Male *argutula* reference specimens had been collected in Florida and Texas; females had been collected in Texas, Mexico and Florida. Male *magna* specimens had been collected in New York, Minnesota, Mexico, New Jersey, and Oklahoma; females had been collected in Florida, New Jersey, North Carolina, New York, Connecticut, Maryland and Georgia. The date and location of collection of individual reference birds has been reported (Hamilton 1977).

SPSS (Statistical Package for the Social Sciences) subprogram Discriminant (Nie et al. 1975) was used in reference and research data analysis.

RESULTS

Discriminant function analysis of female and male reference specimens employed 10 and 4 variables, respectively, of the original 16 scores and measurements entered for computation. F levels of the remaining deleted characters proved insufficient for further calculations; hence, these variables were eliminated from further analysis. Means and standard deviations, in addition to discriminant function scores, for individual reference specimens have been reported (Hamilton 1977).

Due to significant numbers of specimens with missing characters the number of variables was reduced without seriously reducing the overall separation of reference birds. The use of only 9 of the original 16 variables yielded almost all of the original statistical separation for the reference males and females (Table 2). Research specimens missing one or more of the "best" nine variables were, therefore, eliminated from further DFA. Although this final analysis resulted in the deletion of 12.58 percent of the original 358 research specimens (20 males and 26 females), the final DFA was believed to be acceptable.

DFA scores were generated for the male and female research specimens in histogram form (Figure 2). Individual DFA scores, and sub-group classifications, resulting from the final DFA of the research birds are in Hamilton (1977).

DISCUSSION

DFA verfied the existence of *S.m. argutula* in southern Illinois. A total of 88 male and 87 female specimens were separated from *magna*, on the basis of the nine scores and measurements utilized. These *argutula* specimens were generally darker in overall coloration, and smaller in total body size than their *magna* counterparts.

Sixty male research specimens reflected DFA scores which positioned them between the *magna* and *argutula* clusters (Figure 2). Of these, 28 were categorized as closest to *magna*, and 32 labeled closest to *argutula*, by DFA. These intermediate specimens were clustered around the midpoints between the sample means. A total of eight female research birds showed DFA scores which placed them in an intermediate position between the *magna* and *argutula* clusters (Figure 2). Of these, six were classified closest to *magna*, and two closest to *argutula*.

The existence of the 68 specimens (21.8 percent of the 312 research specimens utilized in the final analysis) strongly suggested that intergradation was occurring in southern Illinois. These individuals could easily represent first generation intermediates.

The existence of gaps between the clusters of females (Figure 2) tended to imply a low rate of intergrade offspring production. Assuming additive inheritance, these gaps would not be expected to occur if intermediate meadowlarks were common to this area. However, such gaps did not appear in the male data (Figure 2), suggesting a much more substantial rate of intergradation. Perhaps the overall survival rate of fledged intermediate females was significantly less than that of the males. The sex ratio of successfully reared nestlings may have been inclined to favor survival of greater numbers of intermediate males.

In depth examination of the current meadowlark population in southern Illinois might clarify the rate and degree of intergradation. The overall effects relative to population dimensions and percentages of *argutula* and *magna* and intermediate forms could prove revealing.

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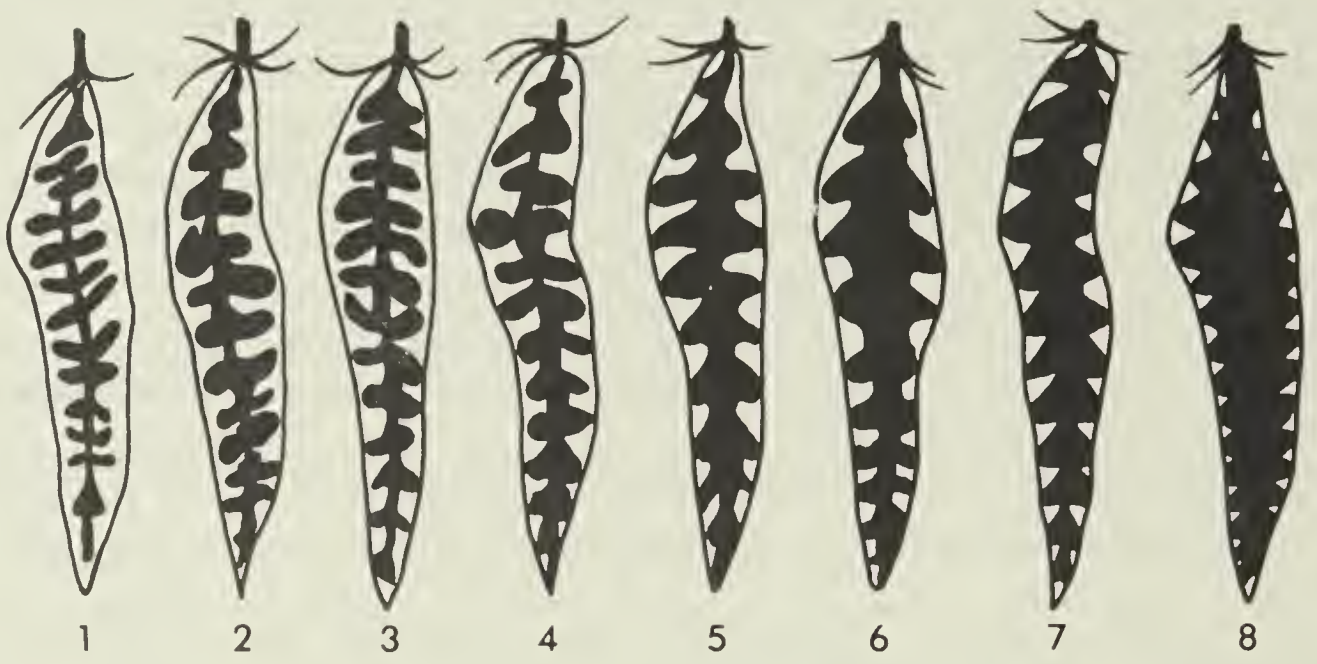


Fig. 1a. Scoring system based on distribution of black barring in the central tail rectrices — CRS.

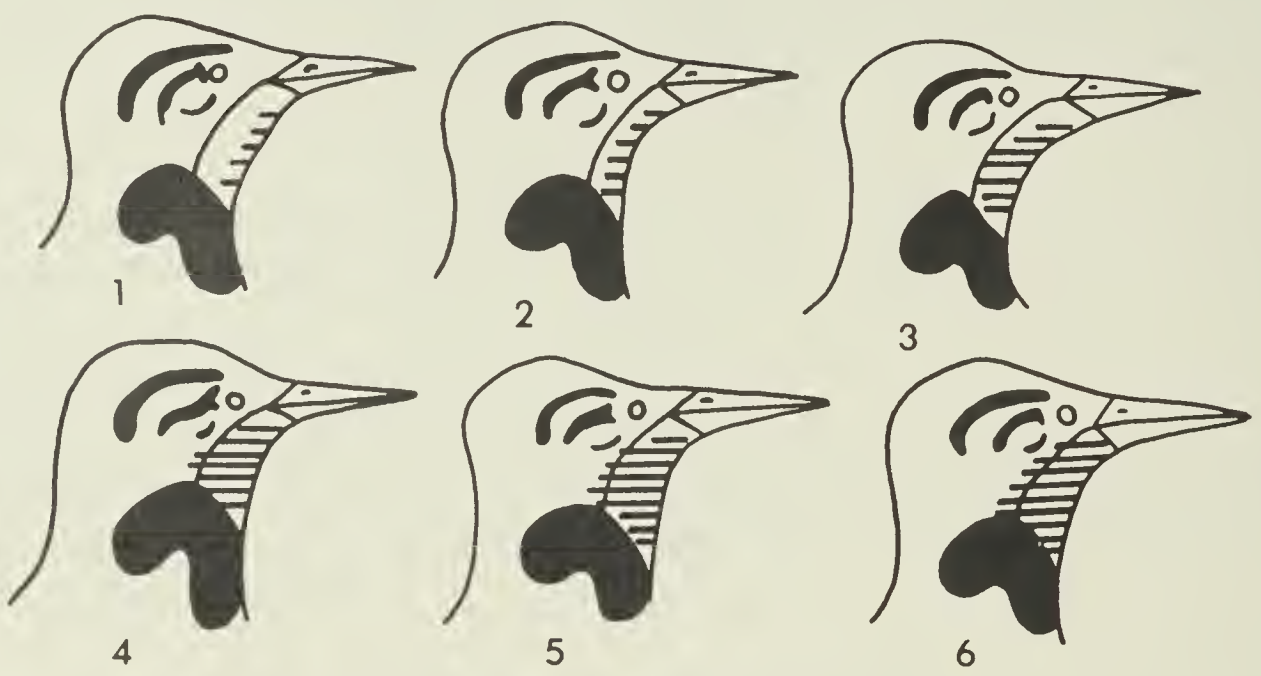
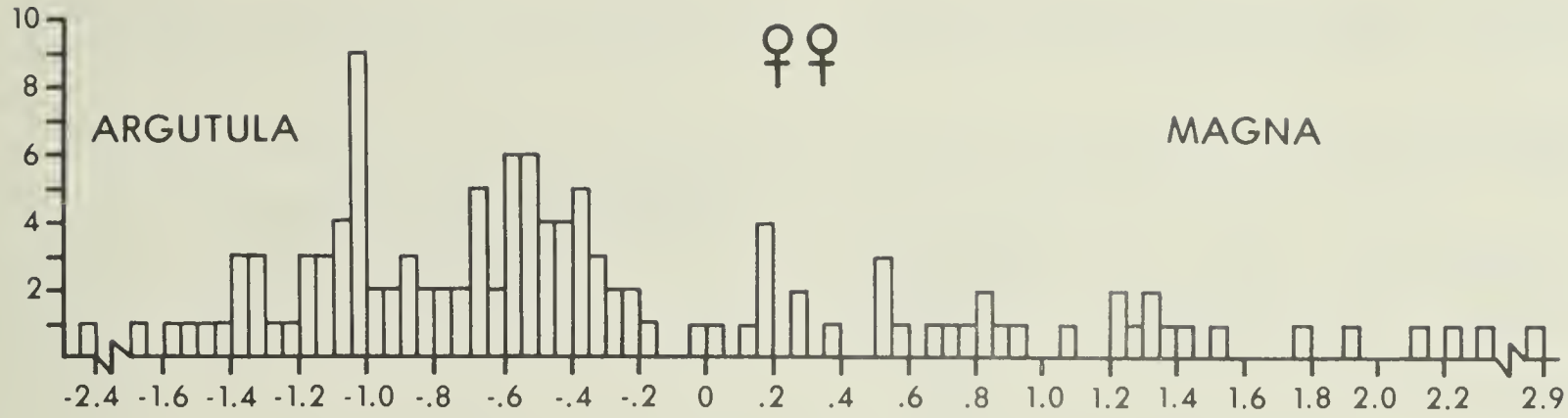


Fig. 1b. Scoring system based on yellow neck color — YCS.

Fig. 1c. Scoring system based on the pattern of markings on feathers from the center of the back — BFS.



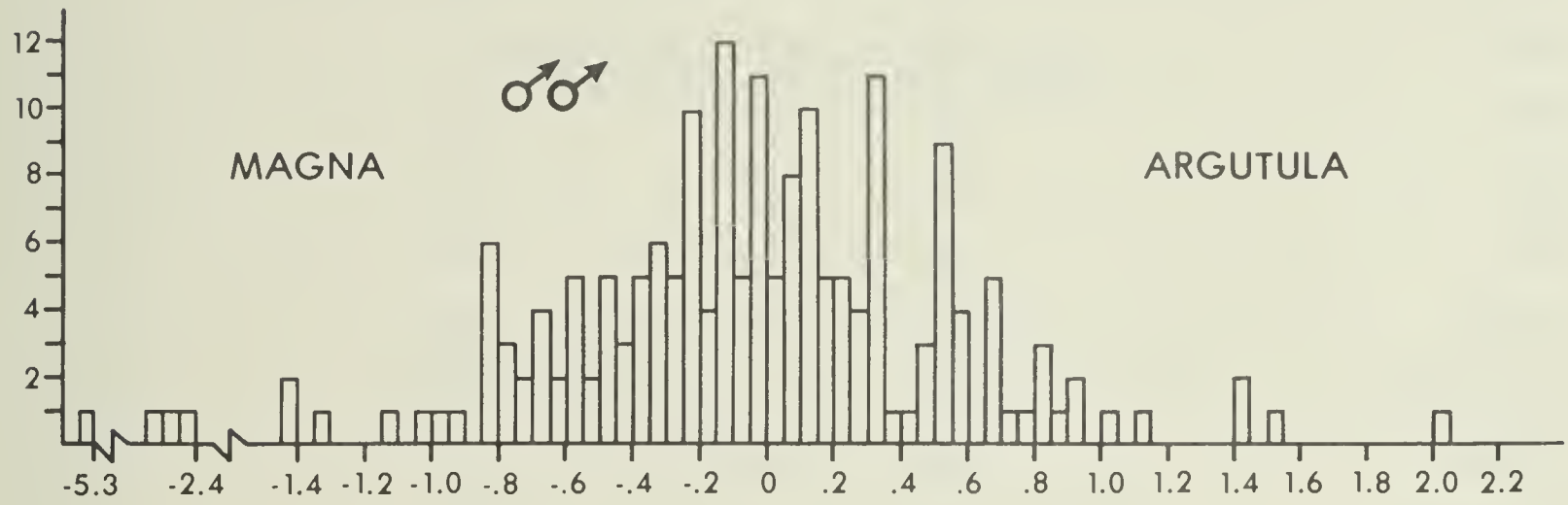


Fig. 2. Discriminant function analysis (DFA) scores for female and male research specimens.

Table 1. Specimens utilized in study

	Numbers collected	
Month	Male	Female
January	25	5
February	25	4
March	17	12
April	13	15
May	14	15
June	13	17
July	10	19
August	15	16
September	12	20
October	18	14
November	27	3
December	20	9
TOTALS:	209	149

Table 2. Statistical results of discriminant analysis of reference meadowlark specimens

Sex	level of analysis	canonical correlation	Wilks' lamda	chi-square	degrees of freedom
Female					
	Initial	0.966	0.0674	62.031	10
	Final	0.928	0.1396	49.232	6
Male					
	Initial	0.951	0.0960	60.936	4
	Final	0.951	0.0960	60.936	4

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SIZE, AGE, AND GROWTH OF AN ALLIGATOR SNAPPING TURTLE, *MACROCLEMYS TEMMINCKI*, FROM ILLINOIS

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ABSTRACT

An adult male *Macroclemys temmincki* (495 mm carapace length) from Union Co., Illinois, is the first verifiable record for the state since 1960. The specimen was approximately 28 years old, and showed relatively uniform growth through its life. The turtle was marked "Contact IL Conservation" with white nail polish, and released at the capture site.

INTRODUCTION

The alligator snapping turtle, *Macroclemys temmincki*, is found in the south-central United States from western Florida to eastern Texas, north to southern Kansas and Missouri, and extending up the Mississippi River Valley to southeastern Iowa and northwestern Illinois (Conant, 1975). It is extremely rare in the northern part of its range (Anderson, 1965; Minton, 1972; Smith, 1961). While it is not included as an endangered or threatened species in Illinois (Kenney, 1978; Morris and Smith, 1981), it has been termed "rare and restricted" in the state (Morris and P.W. Smith, ms).

Other than an unverified sight record for Peoria Co. (Blanchard and Princen, 1976), the last reported specimens for the state were collected in Union and Jackson cos. in 1959 and 1960, respectively (Galbreath, 1961). Previous Illinois records, including those of Galbreath (1961), are summarized by Smith (1961).

On 27 or 28 October 1984, Lance Cantrall captured an adult male *M. temmincki* on the bank of Clear Creek (a small tributary of the Mississippi River), 5 mi. WSW Jonesboro, Union Co., Illinois. The turtle was subsequently given to the Illinois Department of Conservation. It was marked and released at the capture site on 15 November 1984. Before it was released, data on size, age, and growth were recorded. We report this specimen in order to: (1) make available data on growth and age, previously unavailable for the species at the northern part of its range; (2) bring attention to the identification marks; and (3) report a new Illinois locality for the species.

METHODS

All shell measurements are straight-line (i.e., not measured over the shell curvature). Annuli, separating areas of growth, were counted on the left and right second pleural scutes, and verified by counts on other scutes (Dobie, 1971). Areas of growth between annuli were measured to the nearest mm. The specimen was marked by notching the left second and third marginals (counted from the tail) with a triangular file, and by painting "Contact IL Conservation" with white nail polish on the posterior half of the carapace (Fig. 1).

RESULTS

Mensuration data are summarized in Table 1. The turtle's weight was estimated at 32 kg, but this may have been an overestimate (cf. weights recorded by Dobie, 1971). There were 17 annuli on the right second pleural and 28 on the left second pleural. The right pleural scutes were more worn than the left ones. For reasons outlined below, we believe that the left side annulus count is accurate. The turtle, then, was approximately 28 years old (28 growing seasons). Measurements of individual growth increments were relatively uniform (Table 1), indicating uniform growth of the turtle. The central portion of each scute, representing the hatchling scute, was 10 mm, a typical size for scutes of hatchling *Macroclemys* (Dobie, 1971).

DISCUSSION

The discrepancy between left and right side annulus counts is unusual. As noted above, however, the right pleurals were more worn than the left ones, and this obscured some annuli. Dobie (1971) found that male *M. temmincki* did not reach sizes comparable to our specimen until after the 25th growing season; hence we believe that the left side annulus count of 28 is correct.

In Louisiana, alligator snappers grew rapidly for 10-13 years, and thereafter grew more slowly (Dobie, 1971). There is also geographic variation in growth rate, with turtles in Florida growing faster than ones from Louisiana, and ones in southern Louisiana growing more rapidly than ones from east-central Louisiana (Dobie, 1971). Growth is influenced by several factors, but one of the most important ones is duration of the growing season (Dobie, 1971). Since the activity season of reptiles is shorter in Illinois than in more southern states, it is not surprising that the turtle we examined had initially grown comparatively more slowly.

Our specimen did, in general, grow more slowly after the tenth season (Table 1), but the growth rates were remarkably uniform compared to turtles examined

by Dobie (1971), which had an initial mean growth rate of 8 mm/season, but often reaching 10 mm/season, for the first several seasons. Our turtle may have been able to reach its size in the same length of time as southern turtles by maintaining a more uniform growth rate after its fifteenth season than did southern snappers, which decreased to about 3 mm/season (Dobie, 1971: Fig. 8).

Although *M. temmincki* may be highly vagile (Ernst and Barbour, 1972), we believe that the growth rates of the Illinois specimen reported here support the contention that the turtle was a resident of Illinois, or at least of the northern part of the species' range, where growing seasons are short.

Alligator snappers are primarily inhabitants of large rivers and swamps (Ernst and Barbour, 1972). It is evident from our record and others (Galbreath, 1961; Smith, 1961) that they do, at least on occasion, ascend small tributaries of larger rivers. It is not known if they are permanent residents of such habitats.

While we regard *M. temmincki* as extremely rare in Illinois, the species may be more common than available records indicate. Because they are bottom-dwellers of inaccessible habitats (Ernst and Barbour, 1972), they may be less easily collected or observed than other turtle species.

We request that any person observing the turtle we marked notify the Illinois Department of Conservation.

ACKNOWLEDGMENTS

We are grateful to Mary Beth Morris for assistance in recording data, making photographs, and releasing the specimen, and to Joel Hardy for aid in releasing it. We also thank personnel of the Henson Robertson Zoo, Springfield, Illinois, for caring for the specimen before its release. Finally, we thank and commend Lance Cantrall for capturing the turtle alive and for turning it over to the Illinois Department of Conservation.

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Fig. 1. Dorsal view of an adult *Macroclemys temmincki* from Union Co., Illinois, marked for future identification.

Table 1. Measurements (in mm) of an adult male *Macroclemys temmincki* from Union Co., Illinois. Measurements of growth areas are listed from oldest to youngest.

Character	Measurement
Carapace Length	495
Carapace Width	381
Plastron Length	368
Preanal Tail Length	210
Dorsal Tail Length	381
Head Width	145
Growth Areas on Second Pleural	
Right	5, 5, 3, 7, 10, 10, 10, 11, 5, 4, 3, 4, 3, 2, 3, 2, 3 (X = 5.3)
Left	6, 5, 6, 7, 4, 4, 4, 5, 4, 4, 3, 3, 4, 3, 4, 5, 4, 5, 4, 3, 4, 6, 4, 3, 3, 3, 3, 2 (X = 4.1)

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LONG-TERM ECOLOGICAL RESEARCH ON ILLINOIS RIVERS

by
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ABSTRACT

This paper presents the concepts and goals of the Long-Term Ecological Research (LTER) at the Illinois River sites. The "Illinois Rivers" or "large rivers" sites are described with regard to their size, diversity, and dynamic ecosystems. The large river LTER project includes four research components: 1) succession and perturbation, 2) water and sediment fluxes, 3) biotic system structure, and 4) ecosystem function. The research focus of the first several years is given for each component. Significant early findings are also described. These results are being used to develop an integrated model including a hydrologic-hydraulic component and a biological community component. The high productivity of these large rivers is described in terms of plankton, macrophytes, and benthic organisms.

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INTRODUCTION

The Illinois Natural History Survey, Illinois State Water Survey, and Illinois State Geological Survey, located on the campus of the University of Illinois, Urbana-Champaign, and the Illinois State Museum and Western Illinois University are in the third year of a long-term multidisciplinary research project on the ecology of the Mississippi and Illinois Rivers. This is one of the eleven sites around the country where more than 100 scientists and researchers are conducting research on various aspects and components of the natural environment.

The fundamentals of this research are outlined in the program brochure by Halfpenny and Ingraham (1984). Long-Term Ecological Research (LTER) is a program supported by the National Science Foundation's Division of Biotic Systems and Resources. The program was developed during the period from 1976 to 1979 with first open competition for support announced in 1979. LTER acknowledges that:

1) There are ecological phenomena that occur on time scales of decades or centuries, periods of time not normally investigated with research support from the National Science Foundation or other sponsors.

2) Many ecological experiments are performed without sufficient knowledge of the year-to-year variability in the system. Interpretation is, therefore, difficult. This is especially true when the system in which the experiment is performed is not at equilibrium.

3) Long-term trends in natural ecosystems were not being systematically monitored. Unidirectional changes that were observed could not be distinguished from cyclic changes on long time scales.

4) A coordinated network of sites was not available to facilitate comparative experiments. Furthermore, data management was not being coordinated between research sites. Therefore, comparative analyses could not be performed and theoretical constructs could not be conveniently tested.

5) Natural ecosystems were being converted to uses incompatible with ecological research.

6) Advances in ecological research have often treated phenomena at higher or lower levels of organization as constant or insignificant. This problem can be alleviated by performing intensive investigations at single sites, leading to an accumulation of overlapping information. Through time, site specific research will generate increasingly valuable data sets that will reveal pattern and control at several levels of ecosystem organization.

Initial convergence of LTER effort was encouraged by requiring that sites address research efforts in five core areas: 1) pattern and control of primary production; 2) spatial and temporal distribution of populations selected to represent trophic structure; 3) pattern and control of organic matter accumulation in surface layers and sediments; 4) patterns of inorganic inputs and movements of nutrients through soils, groundwater, and surface waters; and 5) patterns and frequency of disturbance to the research site.

The institutions supporting the LTER sites are committed to encouragement of collaborative research by scientists at other institutions. LTER sites are to be considered regional or national research facilities. Scientists who wish to use the sites can contact the project directors directly. Every LTER program has an outside review team which meets at least once a year at the site to evaluate the program and recommend improvements.

Figure 1 shows the locations of the eleven LTER sites. The following list gives the names of the research sites, the general physical features of the sites, and the princpal research organizations involved in the research projects.

H.J. Andrews (Coniferous forest), Oregon State University and U.S. Forest Service.

Cedar Creek Natural History Area (Oak savanna), University of Minnesota.

Central Plains Experimental Range (Grassland), Colorado State University.

Coweeta Hydrological Laboratory (Deciduous forest), University of Georgia and U.S. Forest Service.

Illinois Rivers (Temperate rivers), Illinois State Natural History, Water, and Geological Surveys; State Museum; and Western Illinois University.

Jornada (Desert), New Mexico State University.

Konza Prairie Research Natural Area (Tallgrass prairie), Kansas State University.

Niwot Ridge (Alpine tundra), University of Colorado.

North Inlet (Coastal marine), University of South Carolina.

Northern Lakes (Northern temperate lakes). University of Wisconsin.

Okefenokee National Wildlife Refuge (Freshwater wetland), University of Georgia and U.S. Fish and Wildlife Service.

Illinois Rivers LTER Site

The Illinois Rivers LTER site draws contributions and participation from scientists and engineers from five separate institutions. The major research topics are: succession and perturbation; water, sediment and nutrient budgets in habitat compartments, including mathematical modeling; relationship between community structure and geomorphic structure and hydrologic regime; and sources, sinks, distribution, and processing of organic matter. The main communities within this temperate freshwater environment are: freshwater marsh; northern floodplain forest; off-shore and mud-bottom benthos; submergent, emergent, and floating aquatic plant beds; phytoplankton and zooplankton; and the firm substrate community in swift current.

The Illinois Rivers LTER site encompasses three different locations on two major rivers: Pool 19 and Pool 26 on the Mississippi River, and Peoria Lake on the Illinois River (figure 2).

This research project was initiated in 1981, and data collection began in 1982. The broad objectives of the long-term research are: 1) to explain the basis and controls of productivity in large floodplain rivers, 2) to determine temporal and spatial patterns of nutrient inputs, losses, and utilization, 3) to examine effects of natural and man-made perturbations (including droughts, floods, navigation dams, barge tows, and contaminants) on key species and processes, and 4) to define relationships between community structures and the hydrologic regime and geomorphic structure. Specific research approaches include: 1) reconstruction of historical and pre-historical disturbances using cores from sediments and trees, 2) sampling and modeling of populations of key producers and consumers, 3) sampling and modeling of water, sediment, and carbon flows in habitat compartments, and 4) analyses of successional patterns in both natural floodplain lakes and navigation pools.

The project initially was subdivided into four components: 1) succession and perturbation in the Illinois and Upper Mississippi Rivers, 2) hydrological environment, water, sediment and mathematical modeling, 3) ecosystem biotic structure, and 4) ecosystem function.

The main thrust within Component 1 is to reconstruct the past. Component 2 focuses on the analysis of historical and collected data on the hydrologic environment.

Component 3 deals with spatial and temporal distributions of populations. These three components support the studies of ecosystem function under Component 4. A brief description of major activities within each component is given in the remainder of this paper.

COMPONENT 1. SUCCESSION AND PERTURBATION

What is "long-term" to ecologists may be only "recent" to geologists, but there is a time span of mutual interest. In the Large Rivers LTER project we are developing a 200-year history of the sites from pollen contained in layers of sediment and tree ring chronology. In addition to providing a historical perspective, the physical sciences are proving useful in mapping the biological communities and in modeling the flow of organic carbon in the system. The geologic maps of bottom sediments in the river pools have been used as a predictor for mapping biological communities. For studying the flow of organic carbon we need to consider loss of carbon to bottom sediment, which is a significant factor in those areas of the rivers known to be filling with sediment.

Our three sites have a common geological history but differ significantly in modern geological processes. Our sites, and most of the large river systems in Illinois, were carved by the meltwaters of several episodes of glaciation. Through several cycles the valleys were deepened into bedrock during the period of maximum flow of glacial meltwaters and then partially filled by sediment during post-galcial times. In our sites this process has been accelerated by construction of the navigation lock and dam system and by the increased rate of sediment influx caused by modern agriculture.

Today, Peoria Lake and most of the backwater lakes of the Illinois River are filling with sediment at rates of 1 or more cm per year. This sedimentation provides a record of the introduction and transport of pollutants in the system. An upstream lake (DePue at mile 212) contains sediment with up to 5000 ppm zinc and up to 200 ppm lead, while a downstream lake (Silver at mile 3) contains sediment with concentrations of 120 ppm zinc and 30 ppm lead.

Pool 26 at Alton, Illinois, is not accumulating great quantities of fine-grained sediment, but it is subject to significant changes with the construction of the replacement lock and dam downstream of the existing lock and dam. The bottom sediments in Pool 26 were mapped by Goodwin and Masters (1983), who reported that the course of the Mississippi River has changed little since the development of European-American culture in the Midwest.

Pool 19 is accumulating vast quantities of fine-grained sediment. With the closure of Lock and Dam 19 in 1913, the pool began filling with sediment at the rate of 1.5% of volume per year and continues filling today at the rate of 0.6% per year. Measurement of this overall rate and calculation of the deposition rates of organic carbon in each ecological habitat area are key elements in our modeling efforts. Geological mapping of the full 70-km length of the pool has been completed. Grab samples of bottom sediment from 377 sites, 60 sediment cores, and many bathymetric cross sections were used to define 12 sediment types (Casavant, in preparation) and to prepare a geological map of bottom sediment in the entire pool. There is a significant trend of downstream fining in the sediment, indicative of active accumulation of sediment in the pool. Repetitive measurements of bathymetric cross sections in 1891, 1928, 1936, 1946, and 1983 show substantial aggradation in the

lower one-third of the pool. Sedimentation rates range from highs of 14 cm per year near the downstream dam to zero in the upper end of the pool.

Cesium-137 is one of several isotopes that can be used to provide dates of sediment. This isotope was produced by the atmospheric testing of atomic weapons and began to be deposited in 1954. Deposition ended in 1970 with the end of testing of these weapons. Figure 3 illustrates this history, and figure 4 shows the quantities measured in a sediment core from Millman Lake, a backwater lake on Pool 19. Significant quantities of Cesium-137 were measured in the uppermost 45 cm of sediment in this core, but none was detected in the lower portions of the core. Thus we concluded that the upper 45 cm of sediment was deposited after 1954, probably mostly after 1963, and we can calculate an average sedimentation rate of about 2 cm/year. Similar measurements made on ten other sites have revealed sediment deposition rates ranging from 0.6 to >3.5 cm/year.

COMPONENT 2. HYDROLOGICAL ENRIVONMENT, WATER, SEDIMENT, AND MATHEMATICAL MODELING

The analyses of the water and sediment environment at the LTER project sites include the following:

a. Measure of water and sediment inflow and outflow.
b. Analyses of historical records to determine the past hydrological environment and to predict future changes.
c. Development, modification, and calibration of a water and sediment flow-mathematical model to determine the distribution and pattern of erosion and scour within the river environment and to predict future changes.
d. Determination of the inflow, outflow, and distribution of the carbon and nutrient fluxes through the research sites.

During the last three years, the major research activities within this component were concentrated on Pool 19 of the Mississippi River. Initially data on water and sediment discharges from about 22 tributaries and two main river sites were collected using standard methods (Buchanan and Somers, 1969; Guy and Norman, 1970). Figure 5 shows the locations of these sites. The tributaries range in drainage area from 55 to 11,200 km^2. Pool 19 has a local drainage area of 13,900 km^2, which is 4.5% of the drainage area at Lock and Dam 19. The Skunk River drains 80%, Henderson Creek drains 11.1%, and smaller tributaries drain the remaining 8.9% of the local drainage area. The data on water and sediment inflow and outflow are being utilized to develop a sediment and water budget for Pool 19 (Bhowmik and Adams, in press; Adams and Bhowmik, 1983).

Other data being collected from Pool 19 consist of the measurements of circulation and retention patterns within the channel border areas of the Montrose Flats (Adams and Bhowmik, 1984). Vane and float assemblies are used to collect these data where the flow velocities are extremely low. Presently electromagnetic current meters are also being used to determine the two-dimensional velocity distribution. These data are being collected to determine the impact of local flow patterns on the deposition and retention of sediment, carbon, and other nutrients within this segment of the river that may change the structure and function of biological communities.

At present mathematical models determining the distribution of particulate matter transport and deposition within the pool environment are being calibrated and

verified. Initial emphasis has been on one-dimensional steady state hydrological models, including sediment transport. Two-dimensional models of the transport, scour, and deposition of sediment particles and water movement will be used to obtain necessary details in important habitats.

Some preliminary data on the mixing and sediment and water budget on Pool 26 near the confluence of the Illilnois and Mississippi Rivers have been collected. Data collection at this location will be continued with emphasis on the mixing of the flows from the two rivers.

Other hydrologic data include precipitation and suspended sediment distribution between the main channel and channel border areas, side channels, and sloughs.

Future data collection will include tributary and main channel sampling for water and sediment flows; intensive investigation of the retention mechanism on Montrose flats; determination of erosion, scour, and flow patterns at islands, side channels, and sloughs, especially during high flows; and collection of detailed water and sediment distribution data at selected sites for the verification of the mathematical models.

COMPONENT 3. ECOSYSTEM BIOTIC STRUCTURE

Studies of the biotic structure at the Illinois and Mississippi River LTER sites have centered on the following major areas:

a. Identifying the species composition of the major biotic components of this ecosystem.
b. Examining specific habitats in relation to characteristic biota or temporal utilization by particular biotic groups.
c. Determining longitudinal and latitudinal shifts in density and diversity of organisms at each LTER site.
d. Establishing techniques and sampling locations for continuation or development of long-term biotic data sets.
e. Developing a dynamic, predictive model to simulate short-term transfer of energy through a navigation pool and long-term changes caused by a succession of catastrophic events.

On the basis of previous data and initial studies under the LTER program, a series of sampling stations have been established at each of the LTER study sites. These include 10 in Peoria Lake of the Illinois River, 15 with 10 alternates on Pool 26 on the Mississippi-Illinois Rivers, and 12 with 10 alternates on Pool 19, Mississippi River. These sites include at least one sampling station in each of the major habitat types found in the pools. Unless site specific questions are being evaluated, each station on each pool is sampled at least seasonally.

The initial phases of this research determined the species composition and density of macrophytes, phytoplankton, zooplankton, benthic meiofauna, macroinvertebrates, and fish. These studies indicated that very specific relationships between habitat and species composition occur at all study sites. Thus, channel border areas with a mud substrate may be described as *Musculium* and/or *Hexagenia* macroinvertebrate communities based on their high density and biomass in this habitat. Shallow channel border areas and some backwaters develop relatively monotypic stands of vegetation (J.W. Grubaugh et al., "Production of *Sagittaria latifolia* and

Neulumbo lutea on Pool 19, Mississippi River," paper submitted for publication in Aquatic Botany).

Besides species specific habitat associations, invertebrates also showed strong density and diversity relationships. Due to high densities (up to 100,000 *Musculium*/m^2 and 3000 *Hexagenia*/m^2) and their dominance in channel border areas, biomass is high while diversity is low. In macrophyte beds, dominance and density are low with a corresponding low biomass but high diversity (including mollusks, annelids, and a variety of insects). Phytoplankton are dominated by diatoms and exhibit pronounced seasonality (figure 6d) (Engman, 1984). Zooplankton are dominated by rotifers but with higher densities of Cladocera and copepods in shallow channel border areas (figure 6b) (Pillard,, 1983). Zooplankton also showed temporal variation with maximum densities occurring in fall and longitudinal change with highest density in lower pool reaches (D.A. Pillard and R.V. Anderson, "A survey of the zooplankton of Pool 19, Mississippi River," paper submitted for publication in Hydrobiologia).

Longitudinal distribution of other invertebrates within pools shifts from communities dominated by insects (Hydropsychidae) in the upper pool reaches to a mussel-annelid dominated community in the lower reaches (figure 6a). In general, these trends are true at each of the study sites although specific densities and community compositions vary. For example, Pool 26 usually has lower densities of organisms with a different genus of Hydropsychidae occupying the niche of filtering collectors found on hard substrate (Anderson and Day, in press).

A number of specialized communities have also been described. These include the commercially valuable unionid mussel beds found in the river. From 10 to 26 species of mussels have been collected at the various LTER sites, with the greatest diversity in Pool 19. Densities range from 2 to 40/m^2 depending on continuous or random distribution. The invertebrate drift community supplies a comparatively constant trophic resource in the water column (figure 6c). There are numerous parasitic associations, such as *Plistophora* on rotifers (D.A. Pillard and R.V. Anderson, "A note on the parasitism of Rotifera by *Plistophora* in Pool 19, Mississippi River," paper submitted for publication in American Midland Naturalist), and inquilinistic associations, such as the trichopteran, *Oecetis*, pupation on mussels (Anderson and Vinikour, 1984) and the oligochaete, *Chaetogaster*, and asiatic clam, *Corbicula* (D.J. Holm and R.V. Anderson, "*Chaetogaster limnaei* infesting unionid mollusks and *Corbicula fluminea* in Pool 19, Mississippi River," paper submitted for publication in American Midland Naturalist). Meiofauna, nematodes, and rotifers have been found abundantly in selected habitats particularly associated with organic matter (R.V. Anderson, "Distribution of nematodes in Pool 19, Mississippi River," paper submitted for publication in Hydrobiologia).

Studies of fish/habitat associations on both rivers grew out of a previous long-term electrofishing program on the Illinois River (Sparks and Starrett, 1974). This program included stations at many points along the river but only in main- and side-channel habitats. Its objective was to address biological changes associated with water quality degradation from point sources. The present program still provides this kind of information. For example, in recent years our results have complemented observations of fishermen and fish managers on the upper Illinois River that improvements in the fishery related to improved water quality. By including additional habitats and sampling methods in the program, we now obtain more comprehensive data on entire fish communities in the rivers. Furthermore, standard methods

for obtaining accessory data on water velocity, temperature, dissolved oxygen, conductivity, turbidity, depth, and presence of numerous cover and substrate characteristics have been incorporated into the program to help explain spatial or temporal changes in fish populations.

A subset of the data collected in 1983 was used to examine changes in fish activity in main channel border habitats in the lower Illinois River during a short-term drought and subsequent low discharges. Hoopnet results showed that dominant fishes changed from riverine- to backwater-associated species when current velocities dropped below 0.3 m/sec. When velocities remained below this level, movement of centrarchids between main channel border and backwater habitats appeared to be controlled by preference of fish for cool water. We concluded that during periods of low flow, lower Illinois River main channel borders provide suitable, if not preferred, habitat for species that are usually associated with backwaters. From a broader perspective, the results illustrated that functional roles of floodplain river habitats can be flow dependent even near the low end of the flow spectrum.

In addition to their biological value, most of our results have applications to floodplain fisheries management. A comparison of Illinois and Mississippi River fish populations showed that carp were typically smaller and in poorer condition in the Illinois River. Subsequent age analyses (Lubinski et al., 1984) indicated that Illinois River carp had shorter life spans and grew more slowly after their third year than those in the Mississippi. Evidence compiled from previous studies suggested that these population conditions were most probably related to poor food resources in the Illinois River, and indicated that the carp commercial fishery would benefit from any efforts to restore benthic populations (i.e., fingernail clams and mayflies) to their historical high levels.

Data are being used to produce a model predictive of species interactions, trophic relationships, and habitat associations. Continued sampling at the established long-term sites will be used to validate the model as well as to assess the effect of catastrophic events and long-term succession.

COMPONENT 4. ECOSYSTEM FUNCTION

The goal of this component is to answer the "why" and "how" questions about large rivers. Why are large floodplain rivers so productive, in terms of fisheries for example? Why are the biological community structures the way they are? How does the ecosystem work?

Our approach to answering these questions is to measure and model the flow of carbon through the system. Carbon is fixed by photosynthesis within the aquatic portion of the river itself and introduced as organic matter from the floodplain and tributaries. Carbon can enter food chains, be stored temporarily on the floodplain or bottom of the river, or be permanently lost to the biotic communities by deep burial within sediments.

The form of organic matter is important. Not all forms of organic matter are equally nutritious, and the nutritional value governs rates of utilization and decomposition by organisms and hence the rate at which carbon cycles within the system. The turnover rate of carbon in the leaves of some aquatic plants, from the time the carbon is fixed to the time the leaf senesces and decomposes, is measured in weeks while woody debris takes years to decompose, primarily because the nitrogen con-

tent of wood is too low to support consumers or decomposers which cannot derive nitrogen from the atmosphere or from other organisms. Although the standing crop of wood in the floodplain and bottom of the river is large, the contribution to aquatic food chains is small because the turnover rate is low.

Our measurements have already demonstrated the importance of carbon fixation in aquatic plant beds and marshes along the river. One of the most abundant emergent species, arrowhead (*Sagittaria latifolia*), produces at least 724 grams dry weight of organic matter per square meter per year. This is about half the production rate achieved on fertilized fields of corn (*Zea mays*), but more than most noncultivated terrestrial plants. Our calculations of production for arrowhead and several other aquatic plants will be revised upward because we are just now measuring belowground production of roots and leakage of dissolved carbon from stems and leaves.

We are currently investigating the fate of organic matter produced in plant beds. We already know that it does not accumulate in the sediments, so it is either used by primary decomposers within the beds or exported to other riverine habitats. The Water Survey is investigating secondary circulation patterns and the recurrence intervals of summer storms with strong winds which could generate waves and move organic matter out of plant beds. If this organic matter is exported and does fuel the detritus-based food chains, then aquatic plants provide a pulse of material at a critical time: the summer low flow period when the input of organic matter from floodplain and tributaries is minimal and phytoplankton populations are low.

The field measurements of carbon fixation, transport, and utilization are used in a computer model which simulates the functioning of the river ecosystem. Carbon is the "currency" which is exchanged between components of the biological model (for example, when predators eat prey). Population densities of key species are represented in grams of carbon per unit volume or unit area. The model includes nonliving components, such as dissolved organic carbon. The biological model is driven by a hydrological model which computes water flows and determines whether sediments will be scoured or deposited.

The model is explanatory, rather than expirical, so that any discrepancy between the behavior of the model and the real river leads us to rethink our concepts about how the river ecosystem works. We should be able to verify the capacity of the model to represent rare events (such as droughts and floods), which may produce major or long-lasting effects, because such events will occur during the 30-year life of the project and the response of the system will be measured.

Although the main purpose of the project and the model is to improve our understanding of rivers, both should find practical application in river management. We should be able to predict the likely effects on the river of proposed improvements in waste treatment and soil conservation in the basin and the effects of projected increases in barge traffic.

LTER AND LOCAL EDUCATIONAL INSTITUTIONS

The Illinois Rivers LTER project encompasses multifaceted research activities involving biology, hydrology, geology, chemistry, and other disciplines. Extensive historical data on the Illinois and Mississippi Rivers are available within the three Scientific Surveys, the State Museum, and Western Illinois University. Moreover, detailed data on almost all facets of river ecosystems are being collected by the researchers working on the project. This research not only is producing interesting

and stimulating results, but also has raised a number of research questions and topics that cannot be answered within the present framework of the project. Additional research on these questions should be initiated in cooperation with other investigators.

The Illinois Rivers LTER research team would welcome the opportunity to initiate and develop joint research projects with professors and scientists at other colleges and institutions, especially those located along the Illinois and Mississippi Rivers.

FUTURE OF THE ILLINOIS RIVERS LTER PROJECT

The researchers propose to continue the project for a total of 30 years. The project is reviewed and funded in five-year installments. Although hypotheses and methodological details may change, the basic direction of the research will remain the same with an emphasis on long-term evaluation with related short-term experimentation. It is certain that innovative concepts and interdisciplinary approaches will be required before we can arrive at an intellectually satisfying understanding of the ecology of large rivers.

ACKNOWLEDGMENTS

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Fig. 1. Long Term Ecological Research (LTER) Network

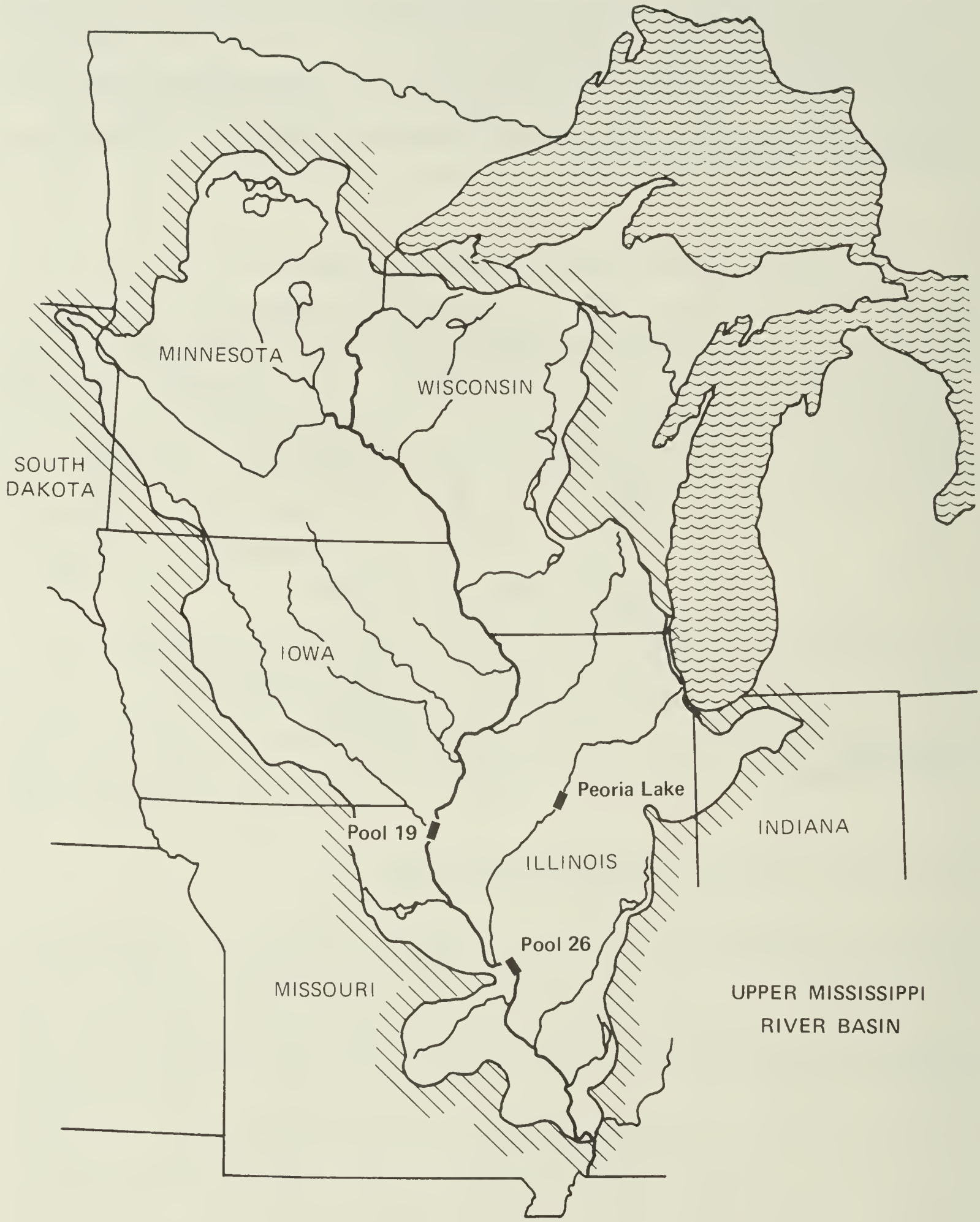

Fig. 2. Illinois Rivers LTER sites

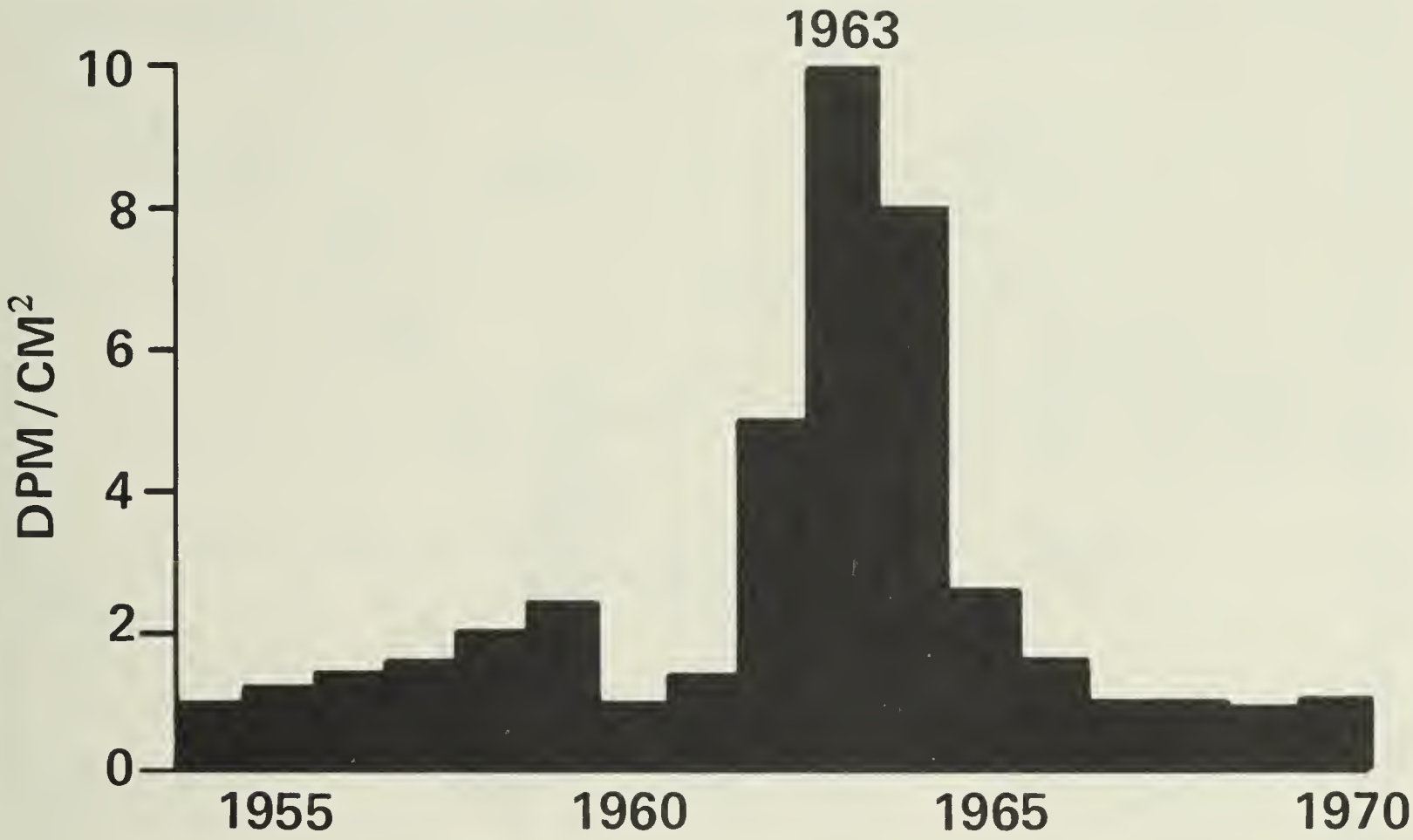

Fig. 3. Atmospheric deposition of Cesium-137 in the Northern Hemisphere

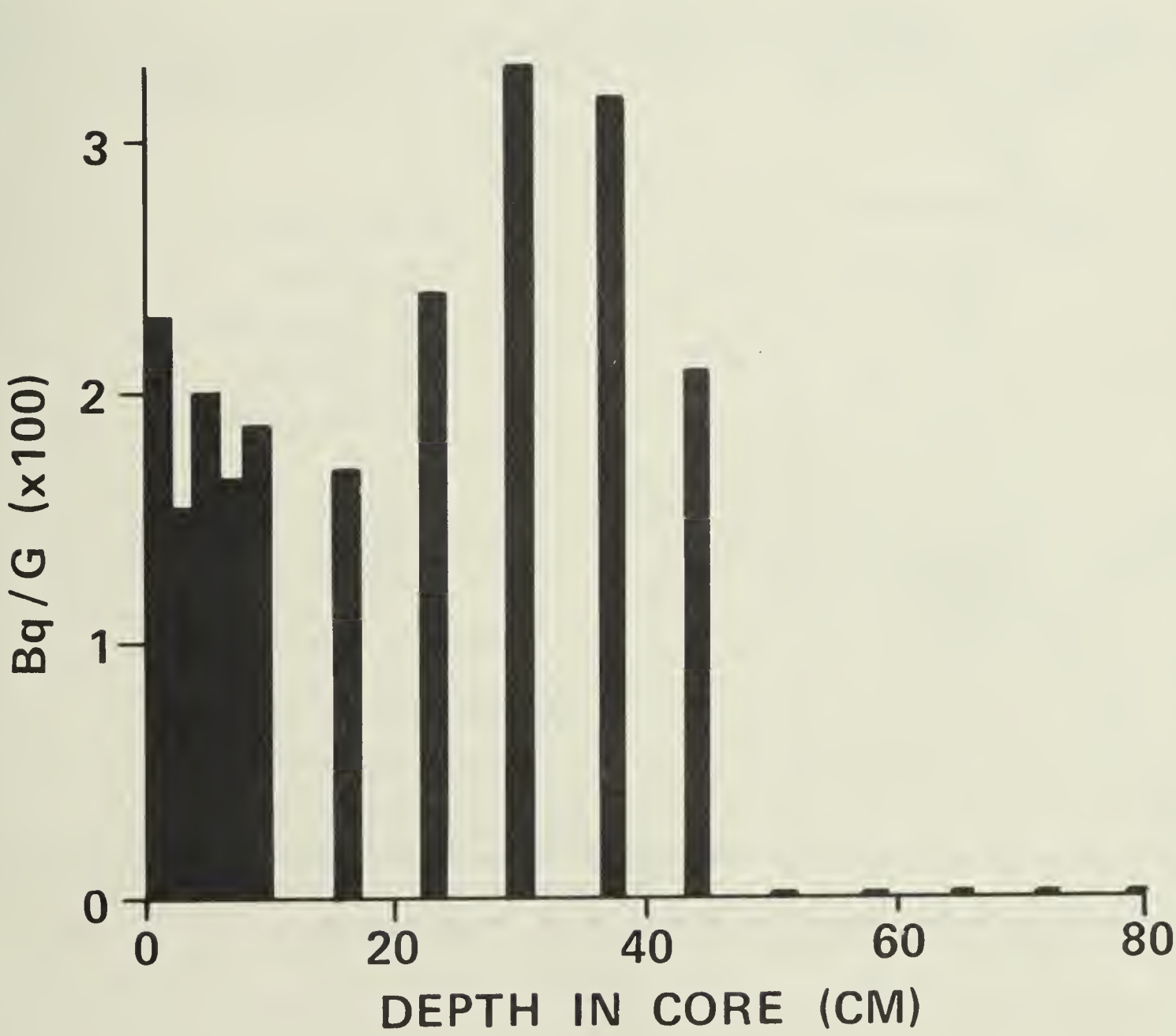

Fig. 4. Cesium-137 profile, Millman Lake, Pool 19

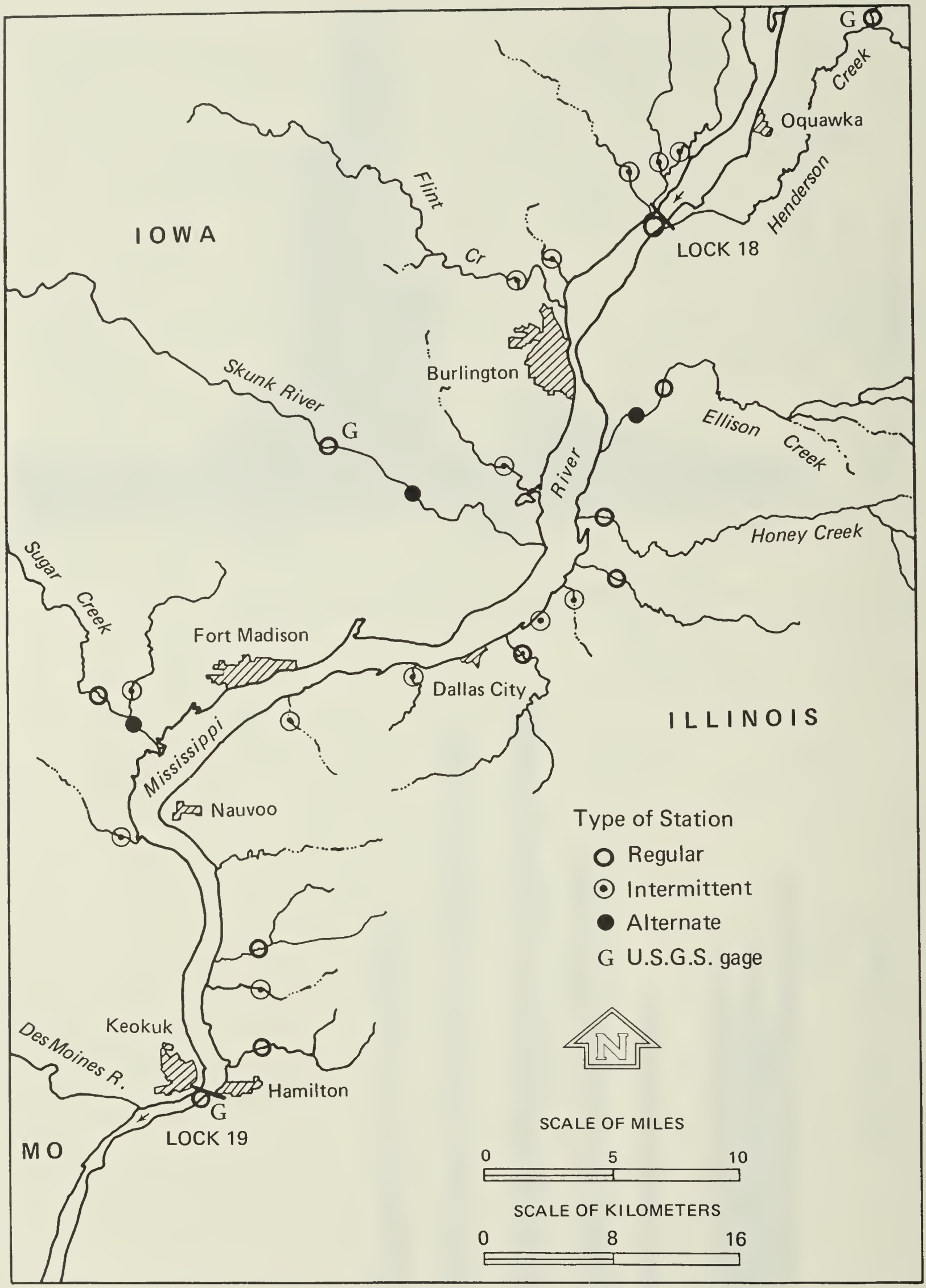

Fig. 5. Pool 19 on the Mississippi River with suspended sediment stations

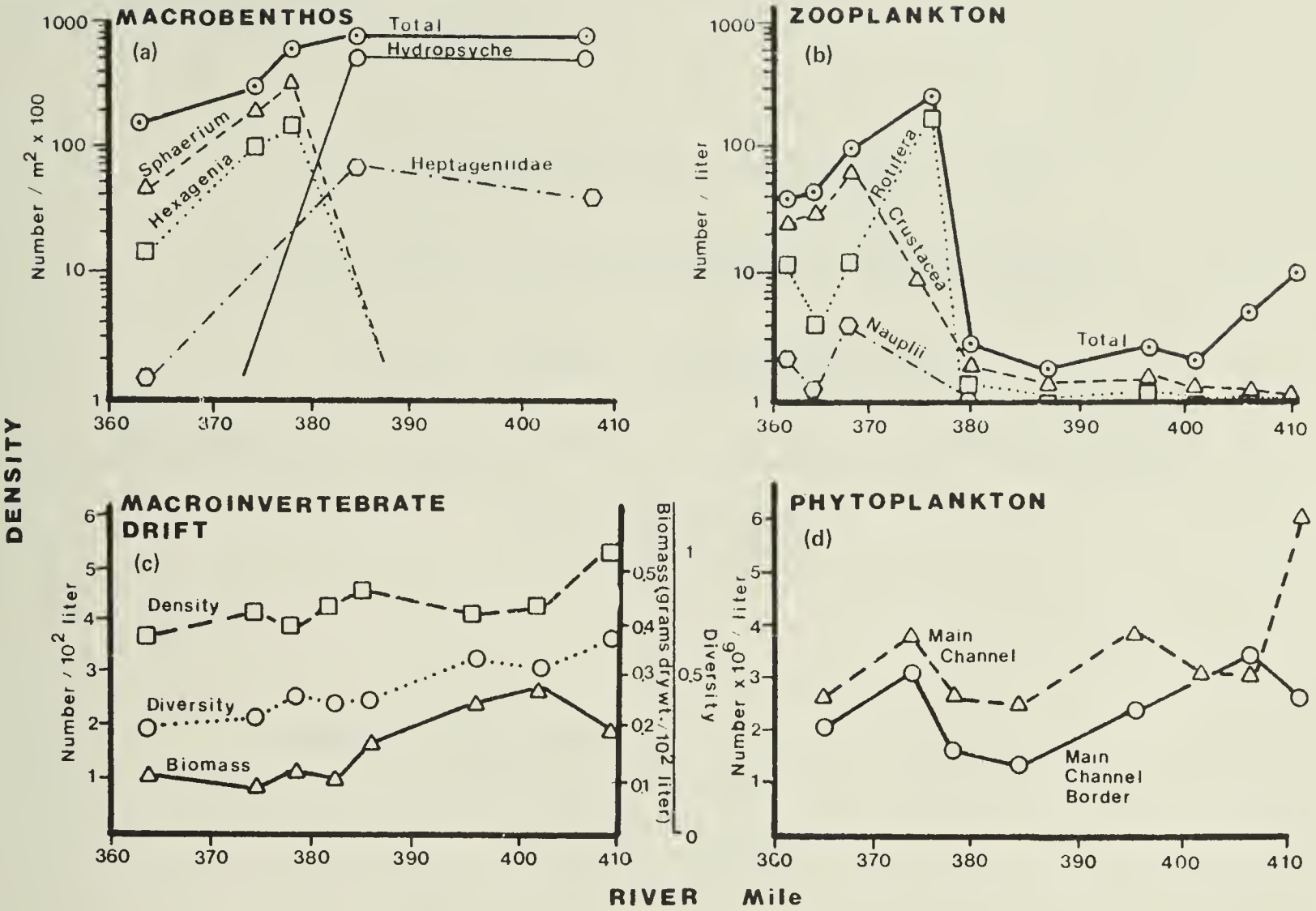

Fig. 6. Longitudinal distribution of major biotic components found in Pool 19, Mississippi River: a) benthic macroinvertebrates, b) zooplankton, c) macroinvertebrate drift, d) phytoplankton

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ANGIOSPERM FLORA OF MILLER-ANDERSON WOODS NATURE PRESERVE BUREAU AND PUTNAM COUNTIES, ILLINOIS

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ABSTRACT

The angiosperm flora of Miller-Anderson Woods Nature Preserve was studied during the growing seasons of 1982 and 1983. Fifteen sample areas located on five natural habitat sites of the Nature Preserve yielded 277 flowering plant taxa, and 67 new county records. Threatened species of *Aster schreberi*, *A. undulatus*, *Filipendula rubra*, *Hydrastis canadensis*, and *Panax quinquefolius* were found in the Nature Preserve. One endangered species of *Castanea dentata* is also reported. The tree canopy consisted of various *Quercus* and *Carya* species. The understory was 70-80% *Acer saccharum*. The dominant shrubs were *Ribes missouriense* and *Rubus occidentalis*. Herbaceous plant taxa were quite diverse. One hill prairie contained *Andropogon gerardi*, various other grasses, and other flowering species.

INTRODUCTION

Miller-Anderson Woods Nature Preserve consists of old growth uplands, ravines, and valley forests of the Grand Prairie Section of the Grand Prairie Natural Division of Illinois (Schwegman, 1973). The original 258 acres of the land were obtained by the Illinois Department of Conservation (IDOC) in 1969. Additional land acquisitions have increased the Nature Preserve to approximately 300 acres. Miller-Anderson Woods is located west of Illinois Route 29 between the junction of Putnam and Bureau Counties (SW 1/4, Sec. 36, T15N, R9E, 4th P.M. and part of W 1/4, Sec. 6, T14N, R10E, 4th P.M.). The Nature Preserve is situated on glacial loess

approximately 13 1/2 miles southeast of the Bloomington Moraine. Soils of the area are predominantly of the Fayette-Strawn-Larson and Dorchester-Calco-Houghton associations.

Miller-Anderson Woods was surveyed by the IDOC in 1977. Five natural habitats were designated by the surveyors as being dry mesic upland forest, mesic upland forest, sedge meadow, successional field, and glacial hill prairie. A brief list of the flowering plants that occurred within the Nature Preserve was included with the survey report. Three threatened taxa were reported for Miller-Anderson Woods; they are: *Panax quinquefolius*, *Hydrastis canadensis*, and *Filipendula rubra*. The cursory angiosperm floral list for Miller-Anderson Woods suggested that a more complete study of the area was needed.

The objectives of the study were to (1) determine the angiosperm flora that occurred within the fifteen sample areas of Miller-Anderson Woods, (2) define habitat(s), (3) assess their abundance, and (4) record their flowering time(s).

MATERIALS AND METHODS

Miller-Anderson Woods was divided into ten habitats (Fig. 1). The habitats were: (A) dry mesic upland forest, (B) south- and southeast-facing wooded slopes, (C) wooded lowland, (D) north-, northeast-, and east-facing wooded slopes, (E) dry old field succession, (F) mesic regrowth forest along stream banks, (G) wet old field succession, (H) sedge meadow, (I) regrowth area along new Illinois Route 29, (J) back water bog, and (K) parking lot. Only the habitats designated A-H and K were investigated. Permanent sample plots were located in each of the previously cited habitats, the only exception being the K site. Some of the larger habitats contained more than one sample plot so as to minimize the exclusion of a particular plant. Each square-shaped plot contained 100 square meters of area. Plots were aligned in a north-south direction with a Lensatic Compass and located away from disturbed areas to avoid any edge effect.

Angiosperm plant specimens were collected on a bi-weekly basis from the middle of March until the middle of October during 1982 and 1983. Plant identifications were determined using the texts of Fernald (1950), Gleason (1952), Harlow (1946), Hitchcock (1951), Jones (1963), Mohlenbrock (1975), Mohlenbrock and Ladd (1978), Sheviak (1981), and Steyermark (1963). At the time of collection, each plant cited in the study was recorded according to habitat, relative abundance, and flowering date(s) if observed. The latter categories are found after each species name in the annotated floral list (Table 1). Relative abundance values were rare = <12, occasional = 12-25, and abundant = >25 plants/plot or area. These numbers represent species numbers within the sample plot(s) or area of the habitats and not the total abundance of the habitat(s). Additional symbols used in the annotation process are (*) threatened plants; (**) endangered plants; (+) Bureau county new record; (+ +) Putnam county new record; (+ + +) a new record for both counties. The majority of taxa cited within this paper were pressed, dried, mounted on herbarium sheets, labeled, and placed in the Bradley University Herbarium.

Three categories of plants were exempt from collection in this study. The exempt categories were: (1) endangered, (2) threatened, and (3) non-threatened but scarce species (one specimen in a plot). Colored 35 mm photographic slides were made of the exempt taxa using a Cannon AE1 camera. The photographic slides are housed in the Bradley University Herbarium.

RESULTS AND DISCUSSION

A total of 72 families, 185 genera, and 277 species of angiosperms were identified from Miller-Anderson Woods Nature Preserve. The families best represented in the Nature Preserve were the Compositae (43 spp.), the Graminae (21 spp.), and the Leguminosae (18 spp.).

There were 468 species identified from the different sample sites. These species have been collated according to habitat (Table 2). The discrepancy between species numbers recorded in Table 1 and the species habitat numbers recorded in Table 2 is due to a plant growing in more than one location.

Wooded lowland (4) and mesic regrowth forest along stream banks(8) plots contained the highest number of species. Threatened specimens of *Panax quinquefolius* L. and *Hydrastis canadensis* L. were found growing in these plots. Both of these threatened plants have been cited previously for Miller-Anderson Woods. In addition to these two taxa, an unreported and threatened species of *Aster undulatus* L. was identified in the wooded lowland (4) habitat and the parking lot (K) area. An endangered species of *Castanea dentata* (Marsh.) Borkh. was located in the wooded lowland (4) habitat. Dry mesic upland forest (1, 2, 6, 12, 13, 14,) and adjacent south-facing wooded slopes (3, 5) plots had the third and fourth highest number of species. A second unreported and threatened species of *Aster schreberi* Ness. was identified in both of the latter habitats. Reduced numbers of species were recorded for the parking lot (K), north-facing wooded slopes (11), dry old field succession (7), prairie (15), wet old field succession (9), and sedge meadow (10) plots. The threatened *Filipendula rubra* (Hill) Robins was located in the sedge meadow (10) as it had been cited by the survey crew. A total of five threatened and one endangered species of angiosperms were identified from the various sampled areas. In addition, there was a total of 67 new records cited in the study for either Putnam and/or Bureau Counties in Illinois. Table 2 indicates the frequency of species as they occurred in the sample plots of the ten habitats. The largest number of species per habitat occurred in the occasional plant category. The second largest number of species were observed in the abundant category; the lowest in the rare category.

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Table 1. Annotated checklist of angiosperm taxa collected from ten habitat locations within Miller-Anderson Woods Nature Preserve

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ACANTHACEAE

Ruellia humilis Nutt. Prairie. Occasional. July.

ACERACEAE

Acer negundo L. Mesic regrowth forest along stream banks and parking lot. Occasional. May.

A. saccharum Marsh. Dry mesic upland forest and dry old field succession. Abundant. Apr.-May.

ANACARDIACEAE

Rhus glabra L. Dry mesic upland forest. Rare. June-July. (Observed but not collected).

Toxicodendron radicans (L.) Kuntze. Dry mesic upland forest, north-facing wooded slopes, mesic regrowth forest along stream banks, and wet old field succession. Abundant. July.

APOCYNACEAE

+*Apocynum androsaemifolium* var. *medium* Greene. Prairie. Abundant. June.

ARACEAE

Arisaema atrorubens (Ait.) Blume. Dry mesic upland forest, wooded lowland, and south-facing wooded slopes. Abundant. May.

A. dracontium (L.) Schott. Wooded lowland. Rare. May-June. (Observed but not collected).

Symplocarpus foetidus (L.) Nutt. South-facing wooded slopes and sedge meadow. Abundant. May.

ARALIACEAE

+*Aralia racemosa* L. Wooded lowland. Occasional. Sept.

**Panax quinquefolius* L. Dry mesic upland forest and wooded lowland. Occasional to rare. July.

ARISTOLOCHIACEAE

Asarum canadense L. Wooded lowland and dry old field succession. Occasional. May.

ASCLEPIADACEAE

Asclepias syriaca L. Dry old field succession and mesic regrowth forest along stream banks. Abundant. June.

A. verticillata L. Prairie. Occasional. July.

+*A. viridiflora* Raf. Prairie. Rare. July.

BALSAMINACEAE

Impatiens biflora Walt. Sedge meadow. Abundant. Aug.-Sept. (Observed but not collected).

I. pallida Nutt. Dry mesic upland forest and wooded lowland. Occasional. Aug.-Sept.

BERBERIDACEAE

Caulophyllum thalictroides L. South- and north-facing wooded slopes. Rare. May.

Podophyllum peltatum L. Dry mesic upland forest and north-facing wooded slopes. Abundant. May.

BETULACEAE

Ostrya virginiana (Mill.) K. Koch. Wooded lowland. Occasional. Mar.-Apr.

BORAGINACEAE

Lithospermum canescens (Michx.) Lehm. Prairie. Abundant. May.

Mertensia virginica (L.) Pers. Wooded lowland. Rare. May.

CAMPANULACEAE

Campanula americana L. Wooded lowland, mesic regrowth forest along stream banks, and wet old field succession. Occasional. July.

Lobelia siphilitica L. Wooded lowland and wet old field succession. Occasional. Aug.

+*L. spicata* Lam. Prairie. Occasional. May.

+*L. spicata* var. *leptostachys* (A.DC.) Machenz. & Bush. Prairie. Occasional. May.

+*Specularia perfoliata* (L.) A.DC. Mesic regrowth forest along stream banks, and parking lot. Occasional. June.

CAPPARIDACEAE

Polanisia doedecandra (L.) DC. Prairie. Rare. Aug.

CAPRIFOLIACEAE

+*Diervilla lonicera* Mill. Dry mesic upland forest, south- and north-facing wooded slopes, and mesic regrowth forest along stream banks. Abundant. Aug.

CARYOPHYLLACEAE

Cerastium vulgatum L. Parking lot. Occasional. July.

CHENOPODIACEAE

Chenopodium hybridum L. South-facing wooded slopes. Occasional. July.

COMMELINACEAE

Tradescantia ohiensis Raf. Prairie, south- and north-facing slopes. Occasional. May.

COMPOSITAE

Achillea millefolium L. Dry old field succession and mesic regrowth forest along stream banks. Occasional. July-Aug. (Observed but not collected).

Ambrosia artemisiifolia L. Dry old field succession and mesic regrowth forest along stream banks. Occasional. Aug.

A. trifida L. Dry old field succession and mesic regrowth forest along stream banks. Occasional. Sept. (Observed but not collected).

Antennaria plantaginifolia (L.) Hook. North-facing wooded slopes. Occasional. Apr.-May. (Observed but not collected).

+*Aster cordifolius* L. Wooded lowland and parking lot. Occasional. Sept.

+*A. laevis* L. Wooded lowland, mesic regrowth forest along stream banks, parking lot. Occasional. Sept. (Observed but not collected).

A. novae-angliae L. Wet old field succession and sedge meadow. Occasional. Sept.

A. sagittifolius var. *drummondi* Shin. South- and north-facing wooded slopes. Occasional. Sept. (Observed but not collected).

A. schreberi Nees. Dry mesic upland forest, south- and north-facing wooded slopes. Occasional. Sept.

+*A. sericeus* Vent. Prairie. Abundant. Sept.

A. shortii Lindl. Wooded lowland and parking lot. Occasional. Sept.

*+*A. undulatus* L. Wooded lowland and parking lot. Rare. Sept.

Bidens discoidea (Torr. & Gray) Britt. Sedge meadow. Occasional. Sept.

+ + +*Boltonia latisquama* var. *decurrens* (Torr. & Gray) Fern. & Grisc. Wet old field succession and sedge meadow. Occasional. Sept.

Brickellia eupatorioides (L.) Shinners. Wet old field succession. Occasional. Sept.

+*Cacalia atriplicifolia* L. Dry mesic upland forest. Occasional. Sept. (Observed but not collected).

Cirsium discolor (Muhl.) Spreng. Wet old field succession and sedge meadow. Rare. Sept.

+*C. pumilum* (Nutt.) Spreng. Prairie. Occasional. June. (Observed but not collected).

C. vulgare (Savi) Tenore. Wet old field succession and mesic regrowth forest along stream banks. Occasional. Sept.

Coreopsis palmata Nutt. Prairie. Occasional. June.

Echinacea pallida Nutt. Prairie. Abundant. June.

Erigeron annuus (L.) Pers. North-facing wooded slopes, mesic regrowth forest along stream banks, and parking lot. Abundant. May.

Eupatorium fistulosum Barratt. Wet old field succession and sedge meadow. Abundant. July.

E. rugosum Houtt. Wet old field succession. Occasional. Sept.

+*E. sessilifolium* L. Dry mesic upland forest. Occasional. Aug.

Helianthus grosseserratus Martens. Wet old field succession and sedge meadow. Occasional. Sept.

+*H. tuberosus* L. Wet old field succession. Occasional. Aug.

+ *Hieracium scabrum* Michx. Dry old field succession and mesic regrowth forest along stream banks. Occasional. July.

Lactuca canadensis L. North-facing wooded slopes and mesic regrowth forest along stream banks. Occasional. July.

+ *Prenanthes alba* L. South-facing wooded slopes. Occasional. Sept.

Ratibida pinnata (Vent.) Barnh. Prairie. Occasional. July.

+ *Rudbeckia subtomentosa* Pursh. North-facing wooded slopes. Occasional. July.

R. triloba L. North-facing wooded slopes and mesic regrowth forest along stream banks. Occasional. July. (Observed but not collected).

+ *Senecio obovatus* Muhl. South-facing wooded slopes. Occasional. June.

S. plattensis Nutt. Dry old field succession and mesic regrowth forest along stream banks. Abundant. June.

Solidago altissima L. Prairie. Occasional. Sept.

S. canadensis L. Wet old field succession. Abundant. Sept.

S. flexicaulis L. Wooded lowland. Rare. Aug.

S. patula Muhl. Sedge meadow. Occasional. Sept.

Taraxacum laevigatum (Willd.) DC. Dry old field succession, mesic regrowth forest along stream banks and wet old field succession. Occasional. May.

T. officinale Weber. Mesic regrowth forest along stream banks and parking lot. Abundant. May.

+ *Tragopogon pratensis* L. Dry old field succession and mesic regrowth forest along stream banks. Occasional. June.

Verbesina alternifolia (L.) Britt. Mesic regrowth forest along stream banks and parking lot. Occasional. Aug.

CONVOLVULACEAE

+ *Convolvulus sepium* L. South-facing wooded slopes, mesic regrowth forest along stream banks, wet old field succession, and parking lot. Occasional. July.

Cuscuta pentagona Engelm. Sedge meadow. Abundant. June.

+ +*Ipomoea coccinea* L. Sedge meadow. Occasional. Sept.

+ *I. pandurata* (L.) G.F.W. Mey. Dry old field succession. Occasional. July.

CORNACEAE

Cornus drummondi C.A. Mey. Dry old field succession, mesic regrowth forest along stream banks, wet old field succession, and parking lot. Abundant. June.

CORYLACEAE

Corylus americana Walt. Wooded lowland. Rare. Mar.-Apr.

CRUCIFERAE

+ *Arabis laevigata* var. *laevigata* Steyerm. Dry mesic upland forest, south- and north-facing wooded slopes. Occasional. May.

+ *A. laevigata* var. *missiouriensis* Steyerm. Dry mesic upland forest and south-facing wooded slopes. Rare. May.

Capsella bursa-pastoris (L.) Medic. Parking lot. Occasional. May. (Observed but not collected).

+ +*Cardamine bulbosa* (Schreb.) BSP. Sedge meadow. Occasional. May.

Dentaria laciniata Muhl. Dry mesic upland forest, south- and north-facing wooded slopes, and wooded lowland. Abundant. May.

CYPERACEAE

Carex albolutescens Schw. Wooded lowland. Occasional. June. (Observed but not collected).

C. albursina Sheldon. Wooded lowland. Abundant. May.

C. artitecta Mack. Dry mesic upland forest. Occasional. May. (Observed but not collected).

C. blanda Dewey. Wooded lowland. Occasional. June.

+ *C. brunnescens* (Pers.) Poir. Dry mesic upland forest. Occasional. May.

C. convoluta Mack. Dry mesic upland forest. Occasional. May.

C. cristatella Britt. Wooded lowland. Occasional. May.

+ *C. gracilescens* Steud. South-facing wooded slopes. Occasional. May.

C. hirsutella Mack. Dry mesic upland forest. Occasional. June. (Observed but not collected).

+ *C. hirtifolia* Mack. Dry mesic upland forest. Occasional. May.

+ *C. tenera* Dewey. Dry mesic upland forest. Occasional. May.

C. tribuloides Wahl. Wooded lowland. Occasional. June.

ELAEAGNACEAE

+ *Elaeagnus umbellata* Thunb. Dry old field succession and mesic regrowth forest along stream banks. Occasional. May-June.

ERICACEAE

+ *Monotropa uniflora* L. Dry mesic upland forest and south-facing slopes. Rare. Sept.

EUPHORBIACEAE

+ *Euphorbia commutata* Engelm. Mesic regrowth forest along stream banks and parking lot. Occasional. Aug.

E. corollata L. Prairie. Abundant. July.

+ *E. heterophylla* L. Mesic regrowth forest along stream banks and parking lot. Occasional. Aug.

E. supina Raf. Mesic regrowth forest along stream banks and parking lot. Occasional. Aug.

FAGACEAE

** + *Castanea dentata* (Marsh.) Borkh. Wooded lowland. Occasional. June-July.

Quercus alba L. Dry mesic upland forest. Occasional. Apr.-May.

Q. imbricaria Michx. Dry mesic upland forest and wooded lowland. Occasional. Apr.-May.

Q. macrocarpa Michx. South- and north-facing wooded slopes, and wooded lowland. Rare. Apr.-May.

+ *Q. muhlenbergii* Engelm. Dry mesic upland forest, south- and north-facing wooded slopes, and wooded lowland. Occasional. Apr.-May.

Q. palustris Muench. Dry mesic upland forest. Occasional. Apr.-May.

Q. rubra L. Dry mesic upland forest. Occasional. Apr.-May.

Q. velutina Lam. Dry mesic upland forest. Occasional. Apr.-May.

GERANIACEAE

Geranium maculatum L. South-facing wooded slopes. Occasional. May.

GRAMINAE

Andropogon gerardi Vitman. Prairie. Occasional. Aug.

+ *Bouteloua curtipendula* (Michx.) Torr. Prairie. Rare. Aug.

Bromus inermis Leyss. Mesic regrowth forest along stream banks and parking lot. Occasional. May.

+ *B. nottowayanus* Fern. South- and north-facing wooded slopes. Rare. June.

B. purgans L. Dry mesic upland forest. Occasional. Aug.

Dactylis glomerata L. Dry old field succession. Occasional. Aug.

Echinochloa crusgalli (L.) Beauv. Wet old field succession. Occasional. June.

Elymus riparius Wiegand. Wooded lowland. Occasional. Aug.

+ *Eragrostis capillaris* (L.) Nees. South-facing wooded slopes. Occasional. June.

Glyceria striata var. *stricta* Fern. Parking lot. Occasional. June.

Muhlenbergia mexicana (L.) Trin. South-facing wooded slopes. Occasional. Aug.

+ *Panicum boscii* Poir. Dry mesic upland forest and south-facing wooded slopes. Occasional. June. (Observed but not collected).

P. capillare L. South-facing wooded slopes. Occasional. Aug.

+ *P. dichotomiflorum* Michx. Mesic regrowth forest along stream banks, wet old field succession, and parking lot. Occasional. Aug.

+ *P. latifolium* L. South-facing wooded slopes. Occasional. June.

P. leibergii (Vasey) Scribn. Dry mesic upland forest. Occasional. May.

Phylaris canariensis L. Wet old field succession. Occasional. Aug. (Observed but not collected).

+ *Poa nemoralis* L. South-facing wooded slopes. Occasional. May.

+ *Schizachryium scoparium* (Michx.) Nash. Prairie. Occasional. Sept.

+ *Sphenopholis nitida* (Biehler) Scribn. South-facing wooded slopes. Occasional. June.

+ *Vulpia octoflora* (Walt.) Rydb. Parking lot. Occasional. June. (Observed but not collected).

HIPPOCASTANACEAE

Aesculus glabra Willd. Wooded lowland. Rare. Apr.-May. (Observed but not collected).

HYDROPHYLLACEAE

Ellisia nyctelea L. Dry mesic upland forest, wooded lowland, and dry old field succession. Rare. May.

Hydrophyllum appendiculatum Michx. Wooded lowland. Abundant. May.

H. virginianum L. Wooded lowland and north-facing wooded slopes. Abundant. May.

HYPERICACEAE

Hypericum punctatum Lam. Prairie. Abundant. June.

+ *H. sphaerocarpum* Michx. Prairie. Occasional. July.

JUGLANDACEAE

Carya cordiformis (Wang.) K. Koch. Dry mesic upland forest, south-facing wooded slopes, and wooded lowland. Occasional. May-June.

C. ovata (Mill.) K. Koch. Dry mesic upland forest, south- and north-facing wooded slopes. Occasional. Apr.-June.

Juglans nigra L. South-facing wooded slopes and wooded lowland. Occasional. May. (Observed but not collected).

LABIATAE

+ + + *Blephila hirsuta* (Pursh) Benth. Mesic regrowth forest along stream banks, sedge meadow, and parking lot. Rare. July.

Leonurus cardiaca L. Mesic regrowth forest along stream banks and parking lot. Occasional. June.

+ *Mentha cardiaca* Gerarde ex Baker. Mesic regrowth forest along stream banks. Rare. June.

+ *M. piperita* L. Mesic regrowth forest along stream banks. Occasional. Sept.

Monarda fistulosa L. Mesic regrowth forest along stream banks and parking lot. Occasional. July.

Nepeta cataria L. Dry old field succession, mesic regrowth forest along stream banks, and parking lot. Occasional. July. (Observed but not collected).

Prunella vulgaris L. Mesic regrowth forest along stream banks, wet old field succession, and parking lot. Occasional. July.

+ *Scutellaria ovata* Hill. Dry mesic upland forest. Rare. June.

+ *S. parvula* Michx. Prairie. Rare. May.

Stachys palustris L. Dry mesic upland forest. Rare. Aug.

S. tenuifolia var. *hispida* (Pursh) Fern. Sedge meadow. Rare. July-Sept.

Teucrium canadense L. Mesic regrowth forest along stream banks and parking lot. Occasional. July.

LAURACEAE

+ *Sassafras albidum* (Nutt.) Nees. Dry mesic upland forest. Occasional. May. (Observed but not collected).

LEGUMINOSAE

Amphora canescens Pursh. Prairie. Occasional. July.

Amphicara bracteata (L.) Fern. Wooded lowland. Occasional. Sept.

+ *Astralagus trichocalyx* Nutt. Prairie. Rare. Aug.

Cercis canadensis L. North-facing wooded slopes and mesic regrowth forest along stream banks. Occasional. May.

+ *Desmodium canadense* (L.) DC. Wet old field succession. Occasional. July.

D. cuspidatum (Muhl.) Loud. Dry mesic upland forest. Occasional. July.

D. glutinosum (Muhl.) Wood. Dry mesic upland forest. Occasional. June.

Medicago lupulina L. Dry old field succession, mesic regrowth forest along stream banks, and parking lot. Abundant. May.

M. sativa L. Dry old field succession and mesic regrowth forest along stream banks. Abundant. July. (Observed but not collected).

Melilotus alba Desr. Dry old field succession, mesic regrowth forest along stream banks, and parking lot. Abundant. June.

M. officinalis (L.) Lam. Dry old field succession, mesic regrowth forest along stream banks, and parking lot. Abundant. June.

Petalostemum purpureum (Vent.) Rydb. Prairie. Occasional. July.

+ *Psoralea tenuiflora* Pursh. Prairie. Occasional. June.

+ *Robina pseudoacacia* L. Wooded lowland. Occasional. May-June.

Tephrosia virginiana (L.) Pers. Prairie. Rare. June-July.

Trifolium campestre Schreb. Dry old field succession. Occasional. June.

T. pratense L. Dry old field succession and mesic regrowth forest along stream banks. Occasional. June.

T. repens L. Dry old field succession. Rare. June. (Observed but not collected).

LILIACEAE

Allium tricoccum Ait. Wooded lowland. Occasional. May.

Erythronium albidum Nutt. Wooded lowland. Abundant. May.

+ *Lilium michiganense* Farw. Sedge meadow. Rare. July.

+ *L. philadelphicum* L. Wooded lowland. Rare. June. (Observed but not collected).

Smilacina racemosa (L.) Desf. Wooded lowland, south- and north-facing wooded slopes. Occasional. May-June.

+ *S. stellata* (L.) Desf. Sedge meadow. Rare. Apr.-May.

Trillium flexipes Raf. Wooded lowland. Abundant. May.

T. recurvatum Beck. Dry mesic upland forest, wooded lowland, and dry old field succession. Abundant. May.

Uvularia grandiflora Sm. Dry mesic upland forest, south- and north-facing wooded slopes. Occasional. May.

MALVACEAE

Malva neglecta Wallr. Dry old field succession, mesic regrowth forest along stream banks, and parking lot. Occasional. June-Sept. (Observed but not collected).

MENISPERMACEAE

Menispermum canadense L. Dry mesic upland forest. Occasional. Aug.

MORACEAE

Humulus lupulus L. Mesic regrowth forest along stream banks and parking lot. Rare. Sept.

+ *Morus alba* L. Wooded lowland. Rare. Aug.

M. rubra L. Wooded lowland and mesic regrowth forest along stream banks. Occasional. June.

OLEACEAE

Fraxinus pennsylvania var. *subintegerrima* (Vahl) Fern. Wooded lowland, mesic regrowth forest along stream banks, and parking lot. Occasional. June. (Observed but not collected).

ONAGRACEAE

Circaea quadrisulcata (Maxim.) Franch. & Sav. Wooded lowland. Occasional. July.

Gaura biennis L. Mesic regrowth forest along stream banks and parking lot. Occasional. Sept.

Oenothera biennis L. Mesic regrowth forest along stream banks and parking lot. Occasional. Sept.

ORCHIDACEAE

Orchis spectabilis L. South-facing wooded slopes and wooded lowland. Rare. May.

OXALIDACEAE

Oxalis stricta L. Parking lot. Occasional. June

O. violacea L. South- and north-facing wooded slopes. Rare. May.

PAPAVERACEAE

+ *Dicentra canadensis* (Goldie) Walp. Wooded lowland and north-facing wooded slopes. Rare. May.

D. cucullaria (L.) Bernh. Dry mesic upland forest, north-facing wooded slopes, wooded lowland, and dry old field succession. Abundant. Apr.

Sanguinaria canadensis L. Dry mesic upland forest, south-facing wooded slopes, and wooded lowland. Abundant. Apr.

PHRYMACEAE

Phryma leptostachya L. Wooded lowland. Occasional. July.

PHYTOLACCACEAE

+ *Phytolacca americana* L. Dry mesic upland forest, mesic regrowth forest along stream banks, and parking lot. Occasional. July.

PLANTAGINACEAE

Plantago major L. Parking lot. Occasional. July. (Observed but not collected).

POLEMONIACEAE

+ *Phlox divaricata* var. *laphamii* (Wood) Wherry. South- and north-facing wooded slopes, and wooded lowland. Abundant. May.

POLYGALACEAE

Polygala senega L. Dry mesic upland forest, prairie, and south-facing wooded slopes. Occasional. May.

POLYGONACEAE

Polygonum pensylvanicum L. Mesic regrowth forest along stream banks and parking lot. Occasional. Aug.

+ +*P. punctatum* Ell. Sedge meadow. Occasional. July.

P. scandens L. Mesic regrowth forest along stream banks and parking lot. Rare. Sept.

+*P. virginianum* L. Wooded lowland. Occasional. July.

Rumex crispus L. Dry old field succession and mesic regrowth forest along stream banks. Occasional. June.

+ +*R. orbiculatus* A. Gray. Sedge meadow. Rare. Sept.

PORTULACACEAE

Claytonia virginica L. Dry mesic upland forest, south- and north-facing wooded slopes, wooded lowland, and dry old field succession. Abundant. Apr.

PRIMULACEAE

Lysimachia ciliata L. Sedge meadow. Occasional. June.

RANUNCULACEAE

Actaea pachypoda Ell. Wooded lowland and north-facing wooded slopes. Occasional. May.

Anemone canadensis L. Wooded lowland. Occasional. June.

A. virginiana L. Dry mesic upland forest and south-facing wooded slopes. Rare. July.

+*Anemonella thalictroides* L. South-facing wooded slopes. Rare. May.

Aquilegia canadensis L. North-facing wooded slopes. Rare. May.

+ +*Caltha palustris* L. Dry old field succession and sedge meadow. Occasional. Apr.

Hepatica nobilis var. *acuta* (Pursh) Steyerm. Dry mesic upland forest, wooded lowland, and north-facing wooded slopes. Occasional. Apr.

**Hydrastis canadensis* L. Wooded lowland. Rare. May.

+*Isopyrum biternatum* (Raf.) Torr. & Gray. South-facing wooded slopes and wooded lowland. Abundant. May.

Ranunculus abortivus L. Dry mesic upland forest, south-facing wooded slopes, wooded lowland, and dry old field succession. Occasional. May.

R. septentrionalis Poir. Wooded lowland. Occasional. May.

+*Thalictrum dioicum* L. Wooded lowland. Rare. July.

RHAMNACEAE

Ceanothus americanus L. Dry mesic upland forest. Rare. June.

ROSACEAE

Agrimonia pubescens Wallr. Wooded lowland. Occasional. Sept.

+*Aruncus dioicus* (Walt.) Fern. Prairie. Rare. June.

**Filipendula rubra* (Hill) B.L. Robins. Sedge meadow. Abundant. July.

+*Fragaria virginiana* Duch. Dry old field succession and mesic regrowth forest along stream banks. Abundant. May.

Geum canadense Jacq. Wooded lowland. Occasional. June.

Mallus pumila Mill. Dry mesic upland forest. Rare. May.

Potentilla recta L. Parking lot. Rare. May.

P. simplex Michx. Parking lot. Abundant. May.

Rosa multiflora Thunb. Dry mesic upland forest, south-facing wooded slopes, wooded lowland, dry old field succession, and wet old field succession. Abundant. June.

Rubus allegheniensis Porter. Dry old field succession, mesic regrowth forest along stream banks, and parking lot. Occasional. June. (Observed but not collected).

R. occidentalis L. Dry mesic upland forest, north-facing wooded slopes, and mesic regrowth forest along stream banks. Occasional. May. (Observed but not collected).

RUBIACEAE

Galium aparine L. Dry mesic upland forest, south- and north-facing wooded slopes. Abundant. May.

G. circaezans Michx. Wooded lowland. Occasional. July.

G. concinnum Torr. & Gray. Dry mesic upland forest. Occasional. May.

G. triflorum L. Dry mesic upland forest. Occasional. May.

RUTACEAE

+*Ptelea trifoliata* L. Dry mesic upland forest, south-facing wooded slopes, and wooded lowland. Rare. May.

+*Zanthoxylum americanum* Mill. Dry mesic upland forest. Occasional. June.

SALICACEAE

Populus deltoides Marsh. Prairie and dry old field succession. Rare. June.

+ *Salix discolor* Muhl. Mesic regrowth forest along stream banks. Occasional. Apr.

S. nigra Marsh. Dry and wet old field succession. Abundant. May. (Observed but not collected).

SAXIFRAGACEAE

Mitella diphylla L. Wooded lowland. Rare. May.

+ *Ribes americanum* Mill. Dry mesic upland forest. Rare. June.

R. missouriense Nutt. Dry mesic upland forest and wet old field succession. Abundant. May.

SCROPHULARIACEAE

+ + *Chelone glabra* L. Sedge meadow. Rare. Sept.

Verbascum thapsus L. Dry mesic upland forest, dry old field succession, mesic regrowth forest along stream banks, and parking lot. Occasional. June.

SMILACACEAE

Smilax ecirrata (Engelm.) Wats. South- and north-facing wooded slopes. Occasional. Sept.

S. hispida Muhl. Dry mesic upland forest, south- and north-facing wooded slopes, and mesic regrowth forest along stream banks. Abundant. July.

S. lasioneuron Hook. South-facing wooded slopes. Occasional. June.

+ *S. pulverulenta* Michx. South-facing wooded slopes, wooded lowland, and mesic regrowth forest along stream banks. Rare. May.

STAPHYLEACEAE

Staphylea trifolia L. South-facing wooded slopes and wooded lowland. Rare. May.

TILIACEAE

Tilia americana L. Wooded lowland. Occasional. Aug.

TYPHACEAE

Typha latifolia L. Sedge meadow. Abundant. Aug.

ULMACEAE

Ulmus americana L. Wooded lowland. Occasional. Apr.

U. rubra Muhl. Dry mesic upland forest and wooded lowland. Abundant. Apr.

UMBELLIFERAE

Angelica atropurpurea L. Wet old field succession and sedge meadow. Abundant. May.

Cryptotaenia canadensis (L.) DC. Dry mesic upland forest, wooded lowland, mesic regrowth forest along stream banks, and parking lot. Abundant. May.

Daucus carota L. Dry old field succession, mesic regrowth forest along stream banks, and parking lot. Abundant. July. (Observed but not collected).

Heracleum maximum Bartr. Dry old field succession, mesic regrowth forest along stream banks, and parking lot. Occasional. May.

Osmorhiza claytonii (Michx.) Clark. Wooded lowland. Abundant. May.

+ *O. longistylis* (Torr.) DC. Wooded lowland. Abundant. June.

+ + *Oxypolis rigidior* (L.) Coulter & Rose. Sedge meadow. Occasional. Aug.

Pastinaca sativa L. Dry old field succession, mesic regrowth forest along stream banks, and parking lot. Abundant. June. (Observed but not collected).

Sanicula gregaria Bickn. South-facing wooded slopes and wooded lowland. Occasional. May.

S. trifoliata Bickn. Wooded lowland. Rare. Aug.

+ *Taenidia integerrima* (L.) Drude. South-facing wooded slopes. Rare. May.

URTICACEAE

Parietaria pensylvanica Muhl. South-facing wooded slopes. Rare. Aug.

Pilea pumila (L.) A. Gray. Dry mesic upland forest, south- and north-facing wooded slopes, and wooded lowland. Abundant. July.

Urtica dioica L. South-facing wooded slopes and wooded lowland. Abundant. July. (Observed but not collected).

U. gracilis Ait. Mesic regrowth forest along stream banks and sedge meadow. Occasional. Sept. (Observed but not collected).

VERBENACEAE

Verbena urticifolia L. North-facing wooded slopes, mesic regrowth forest along stream banks, wet old field succession, and parking lot. Occasional. July.

VIOLACEAE

+ *Viola pensylvanica* Michx. Wooded lowland. Occasional. May. (Observed but not collected).

V. sororia Willd. Dry mesic upland forest and wooded lowland. Occasional. May.

VITACEAE

Parthenocissus quinquefolia (L.) Planch. Dry mesic upland forest, south- and north-facing wooded slopes, and wooded lowland. Abundant. June-July. (Observed but not collected).

+ *Vitis aestivalis* Michx. Mesic regrowth forest along stream banks and parking lot. Abundant. June.

+ *V. vulpina* L. Wooded lowland. Occasional. June.

Table 2. Number of plant species collected from the ten habitat locations of Miller-Anderson Woods Nature Preserve

Habitat	Species number	Abundant[1]	Occasional[2]	Rare[3]
Wooded Lowland	80	19	42	19
Regrowth Forest	66	16	46	4
Mesic Forest	64	20	35	9
South-Facing Slopes	56	14	28	14
Parking Lot	47	9	34	4
North-Facing Slopes	37	13	18	6
Dry old Field	37	16	19	2
Prairie	30	6	16	8
Wet old Field	26	8	17	1
Sedge Meadow	25	7	11	7
Total	468	128	266	74

[1]Abundant = >25, [2]occasional = 12-25, and [3]rare = <12 plants/habitat.

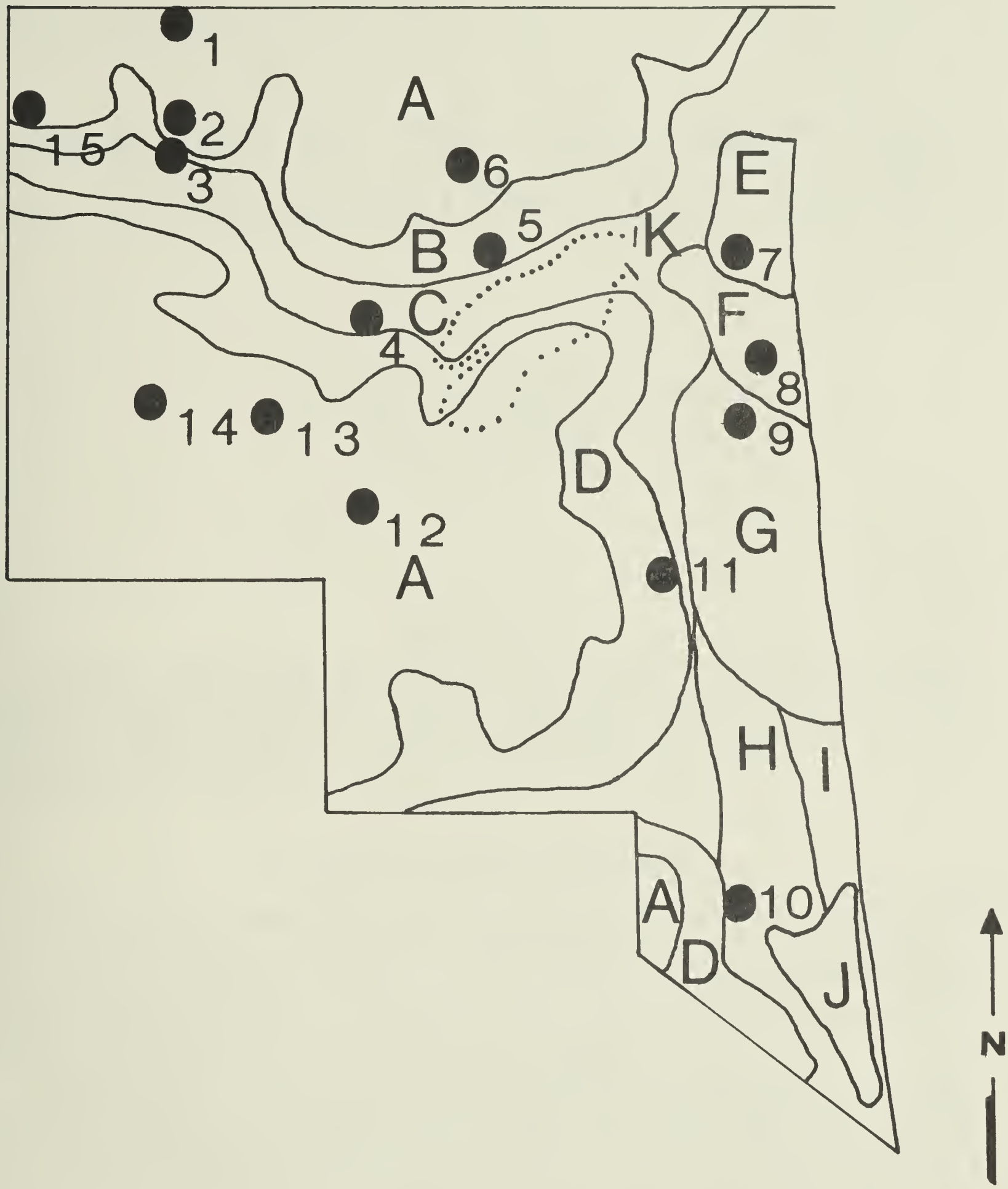

Fig. 1. Habitats and plot numbers of Miller-Anderson Woods Nature Preserve. A. Dry mesic upland forest-1, 2, 6, 12, 13, 14. B. South-facing wooded slopes-3, 5. C. Wooded lowland-4. D. North-facing wooded slopes-11. E. Dry old field succession-7. F. Mesic regrowth forest along stream banks-8. G. Wet old field succession-9. H. Sedge meadow-10. Prairie-15. Parking Lot-K.

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ADDITION TO THE VASCULAR FLORA OF ROCK ISLAND COUNTY, ILLINOIS

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ABSTRACT

Eighteen species of vascular plants have been collected and reported as county records for Rock Island County, Illinois. Description, location, habitat, date collected and collector have been noted for each specimen. The specimens have been deposited in the herbarium at Western Illinois University.

MATERIALS AND METHODS

Plant specimens were collected in the field and later identified with the aid of references (Mohlenbrock 1975, Jones 1963, Fernald 1950, and Gleason 1952). It was tentatively determined whether or not a species was a county record by referring to Mohlenbrock 1978 and tentative records were confirmed by correspondence with Dr. Robert Mohlenbrock in the fall of 1983.

Each specimen was given a collection number and was recorded by date, scientific name (nomenclature according to Mohlenbrock 1975), family name, and common name in the personal collection record book of the author. The specimens were pressed and the following information was recorded for each: scientific, family, and common names; brief description of the plant; habitat; date collected; legal location to within 40 acres from U.S. Geological Survey quadrangle maps for Rock Island County obtained from Dr. Richard Anderson, Department of Geology, Augustana College; descriptive location and collector. It was also noted if the plant was brought to the author's attention by someone else or if aid was obtained in identification.

The pressed specimenss were deposited in the herbarium at Western Illinois University with Dr. Robert Henry. One copy of the collection information for each specimen was included with the specimen and the original was retained by the author.

RESULTS

FAMILY SPECIES	DATE COLLECTED	LOCATION 1/4 of 1/4	SECTION,	TOWNSHIP,	RANGE
ANARCARDIACEAE					
RHUS AROMATATICA AIT.	6-24-83	NW SE	14	17N	2W
ARACEAE					
ACORUS CALAMUS L.	7-18-83	SE SW	14	17N	1W
CARYOPHYLLACEAE					
SAPONARIA OFFICINALIS L.	7-18-83	NW NE	21	17N	1W
COMPOSITAE					
CHRYSANTHEMUM LEUCANTHEMUM L.	6-14-83	SE SW	22	17N	1W
DIPSACACEAE					
DIPSACUS LACINIATUS L.	7-18-83	NE SE	11	17N	1W
FAGACEAE					
QUERCUS MUHLENBERGII ENGLEM.	6-24-83	NW SE	14	17N	2W
LABIATAE					
TEUCRIUM CANADENSE L. Var. OCCIDENTALE (GRAY) McCLINTOCK & EPLING.	7-8-83	NE SW	12	17N	1W
LEGUMINOSAE					
GYMNOCLADUS DIOCA (L.) K. KOCH	6-13-83	NW NE	14	17N	2W
VICIA VILLOSA ROTH	6-20-83	NW SE	15	17N	1W
LYTHRACEAE					
LYTHRUM SALICARIA L.	7-18-83	NE/SE SE	14	17N	1W
MALVACEAE					
NAPAEA DIOICA L.	7-18-83	SW NE	22	17N	1W

POAACEAE					
PHALARIS ARUNDINACEAE L.	6-20-83 and 7-10-83	NW SE	15	17N	1W
ROSACEAE					
POTENTILLA RECTA L.	6-14-83	SE SW	22	17N	1W
ROSA MULTIFLORA THUNB.	6-14-83	NE SE	23	17N	1W
SCROPHULARIACEAE					
PENSTEMON DIGITALIS NUTT.	6-26-83	SE NE	20	18N	1E
SEYMERIA MACROPHYLLA NUTT.	7-23-83	NW SE	14	17N	2W
SIMAROUBACEAE					
AILANTHUS ALTISSIMA (MILL.) SWINGLE	7-23-83	NW SE	14	17N	2W
UMBELLIFERA					
ZIZIA AUREA (L.) KOCH	6-12-83	SW NW	3	17N	1W

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ERRATUM

BAILEY LIMESTONE (LOWER DEVONIAN) OF SOUTHWESTERN ILLINOIS: A CARBONATE TURBIDITE

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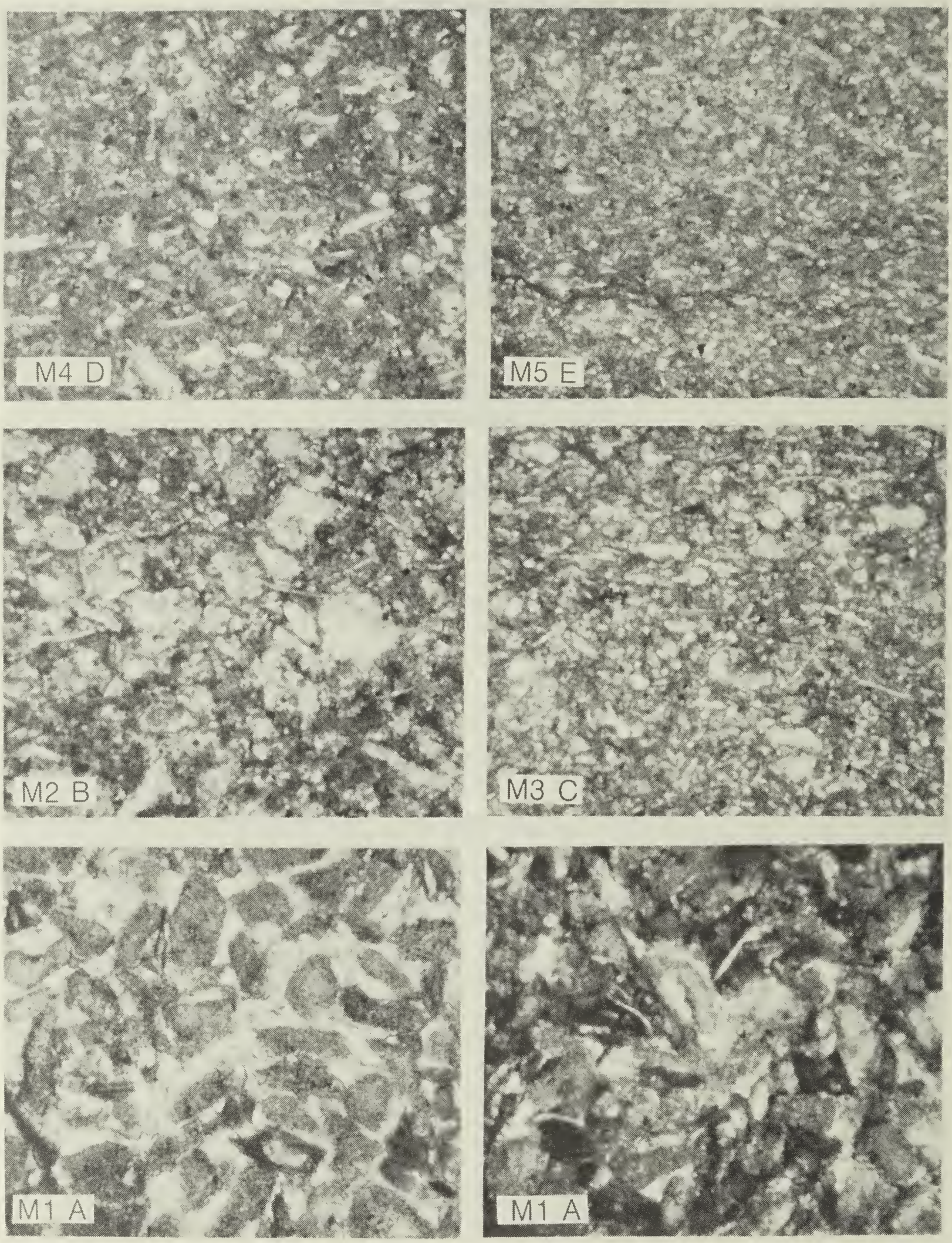

Fig. 3. Photomicrographs of microfacies M1 to M5 in order of superposition (A to E of Bouma sequence). Plane polarized light.

July 25, 1985

AN OPEN LETTER FROM THE EDITOR

Dear Colleagues:

This issue of *TRANSACTIONS* will be the last that I serve as Editor-in-Chief. I have enjoyed my tenure, and learned much. I want to thank the Editorial Board for their excellent help in the review process, Jill Reiher as Editorial Assistant and Patricia A. Zimmerman as Executive Secretary. I also wish to thank the members of the Illinois State Academy of Science and the Illinois State Museum for their unbridled support these past two years. A very special thank you goes to Academy President Marcia A. Miller and Secretary Laurence E. Crofutt.

I have tried to make *TRANSACTIONS* a good product, one responsive to the scientific community it serves. I have not realized all that I sought to change, but am confident that the new Editor-in-Chief, Dr. Anthony M. Garcy, will continue to move *TRANSACTIONS* forward.

May good fortune be your future.

Barry A. Fiedel, Ph.D.

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Information for Contributors

1. Original communications may be sent to: The Editorial office of the "Transactions of the Illinois Academy of Science," Illinois State Museum, Springfield, Illinois 62706.

2. Submission of a paper to the Editors will be held to imply that it has not been published previously except in Abstract form and that if accepted for the Transactions, it will not be published elsewhere in the same form, without the written consent of the Editors.

3. The format of manuscripts should follow the conventional form: Abstract, Introduction, Materials and Methods, Results, Discussion, and Summary. The paper should be prefaced by the abstract appearing beneath the title and the author's name. The abstract should preferably consist of numbered sentences that summarize main facts and conclusions of the paper. Not more than 250 words should be used.

4. Manuscripts should be typewritten with lines doublespaced (see exception #6) on one side of heavy bond paper (8½" × 11") and a left hand margin of not less than 1½". The submission of two manuscripts will facilitate refereeing. The author should also retain a copy.

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